US009341529B2

(12) **United States Patent**
Nishikage et al.

(10) **Patent No.: US 9,341,529 B2**
(45) **Date of Patent: May 17, 2016**

(54) **PRESSURE SENSOR AND METHOD FOR MANUFACTURING PRESSURE SENSOR**

(75) Inventors: **Haruhiko Nishikage**, Kyoto (JP); **Toma Fujita**, Kyoto (JP)

(73) Assignee: **ROHM CO., LTD**, Kyoto (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 200 days.

(21) Appl. No.: **13/503,574**

(22) PCT Filed: **Nov. 4, 2010**

(86) PCT No.: **PCT/JP2010/069550**

§ 371 (c)(1), (2), (4) Date: **Apr. 23, 2012**

(87) PCT Pub. No.: **WO2011/055734**

PCT Pub. Date: **May 12, 2011**

(65) **Prior Publication Data**

US 2012/0205653 A1 Aug. 16, 2012

(30) **Foreign Application Priority Data**

Nov. 4, 2009	(JP)		2009-252903
Nov. 10, 2009	(JP)		2009-256759
Nov. 10, 2009	(JP)		2009-256760
Nov. 12, 2009	(JP)		2009-258710

(51) **Int. Cl.**

H01L 29/04	(2006.01)
H01L 29/10	(2006.01)
H01L 31/036	(2006.01)
G01L 9/00	(2006.01)

(52) **U.S. Cl.**

CPC ***G01L 9/0047*** (2013.01); ***G01L 9/0045*** (2013.01); ***G01L 9/0054*** (2013.01)

(58) **Field of Classification Search**

CPC H01L 29/84; B81C 1/00158
USPC 257/414, 419; 438/50, 51
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,698,785	A	*	12/1997	Rich et al.	73/514.33
5,883,420	A	*	3/1999	Mirza et al.	257/419
5,919,548	A	*	7/1999	Barron et al.	428/138
5,963,788	A	*	10/1999	Barron et al.	438/48
6,012,336	A	*	1/2000	Eaton	B81C 1/00246 73/754
6,087,701	A	*	7/2000	Bergstrom et al.	257/414

(Continued)

FOREIGN PATENT DOCUMENTS

JP	63-175482	7/1988
JP	6-302834	10/1994

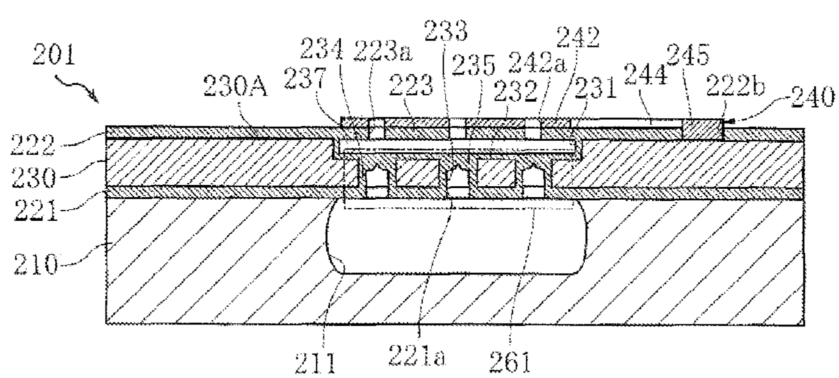
(Continued)

Primary Examiner — John C Ingham
Assistant Examiner — Ismail Muse
(74) *Attorney, Agent, or Firm* — Hamre, Schumann, Mueller & Larson, P.C.

(57) **ABSTRACT**

A pressure sensor **1** comprises a semiconductor substrate **10**, insulating layers **21**, **22**, **23** formed on the semiconductor substrate **10**, a semiconductor layer **30** formed on the semiconductor substrate **10** with the insulating layers **21**, **23** intervening therebetween, and a cavity portion **13** provided between the semiconductor substrate **10** and the semiconductor layer **30**. The portion of the semiconductor layer **30** which overlaps the cavity portion **13** as viewed in a lamination direction serves as a movable portion **31**. The cavity portion **13** is surrounded by the insulating layers **22**, **23**. With this arrangement, the pressure sensor **1** can be manufactured easily with high precision.

8 Claims, 77 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,373,115	B1 *	4/2002	Kolb	G01P 15/0802 257/414
6,465,784	B1 *	10/2002	Kimata	250/332
6,483,111	B1 *	11/2002	Ishikawa et al.	250/338.4
6,541,298	B2 *	4/2003	Iida et al.	438/54
6,541,834	B1 *	4/2003	Shie et al.	257/419
6,645,820	B1 *	11/2003	Peng et al.	438/372
6,777,682	B2 *	8/2004	Ishikawa et al.	250/338.4
7,067,810	B2 *	6/2006	Shigenaka et al.	250/332
7,923,790	B1 *	4/2011	Quevy et al.	257/415
8,304,848	B2 *	11/2012	Suzuki et al.	257/429
2001/0028035	A1 *	10/2001	Iida et al.	250/338.4
2002/0139933	A1 *	10/2002	Iida et al.	250/338.1
2003/0005774	A1 *	1/2003	Suzuki et al.	73/724
2004/0259286	A1 *	12/2004	Dehe et al.	438/50
2005/0052724	A1 *	3/2005	Suzuki	G01H 9/00 359/305
2005/0178967	A1 *	8/2005	Nakaki et al.	250/339.04
2005/0224714	A1 *	10/2005	Akin et al.	250/332
2006/0032039	A1 *	2/2006	Rangsten et al.	29/593
2006/0258039	A1 *	11/2006	Lutz et al.	438/50
2007/0145274	A1 *	6/2007	Iida	250/338.4
2007/0184624	A1 *	8/2007	Mueller et al.	438/303
2007/0202628	A1 *	8/2007	Wuertz	B81C 1/00246 438/53
2009/0020419	A1 *	1/2009	Suzuki et al.	204/400
2009/0026561	A1 *	1/2009	Reichenbach et al.	257/416
2009/0146059	A1 *	6/2009	Nakaki	250/338.4
2009/0200680	A1 *	8/2009	Shinohara et al.	257/773
2009/0206422	A1 *	8/2009	Illing	B81C 1/00158 257/419
2009/0261445	A1 *	10/2009	Sugino	257/463
2009/0266987	A1 *	10/2009	Honda et al.	250/338.4
2009/0275166	A1 *	11/2009	Iinuma	438/72
2009/0321641	A1 *	12/2009	Park et al.	250/338.4
2010/0025584	A1 *	2/2010	Sasaki et al.	250/338.4
2011/0002359	A1 *	1/2011	Benzel et al.	374/178
2011/0073978	A1 *	3/2011	Fujiwara et al.	257/440
2011/0211613	A1 *	9/2011	Herrmann et al.	374/178
2011/0317387	A1 *	12/2011	Pan et al.	361/782
2012/0228497	A1 *	9/2012	Suzuki et al.	250/332
2012/0241613	A1 *	9/2012	Ishii et al.	250/330
2013/0026604	A1 *	1/2013	Hsin et al.	257/603

FOREIGN PATENT DOCUMENTS

JP	9-186347	7/1997
JP	2850558	11/1998

* cited by examiner

FIG.1

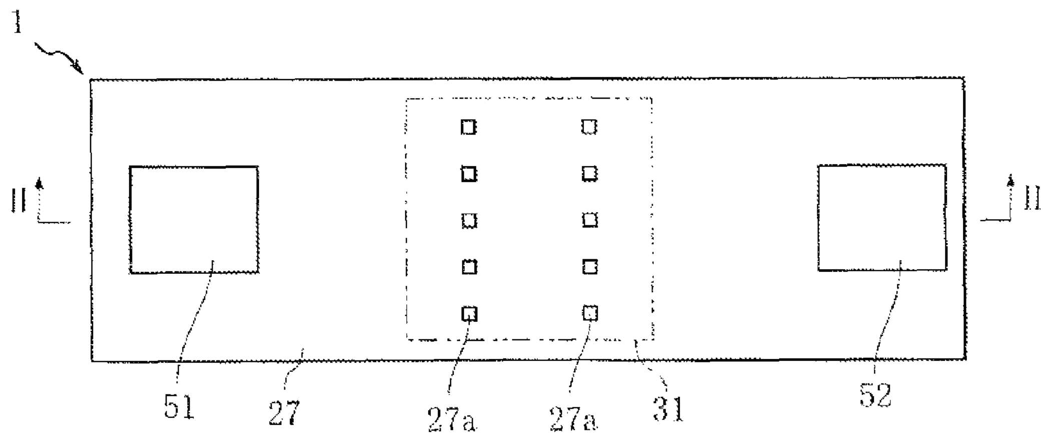

1
II
II
51
27
27a
27a
31
52

FIG.2

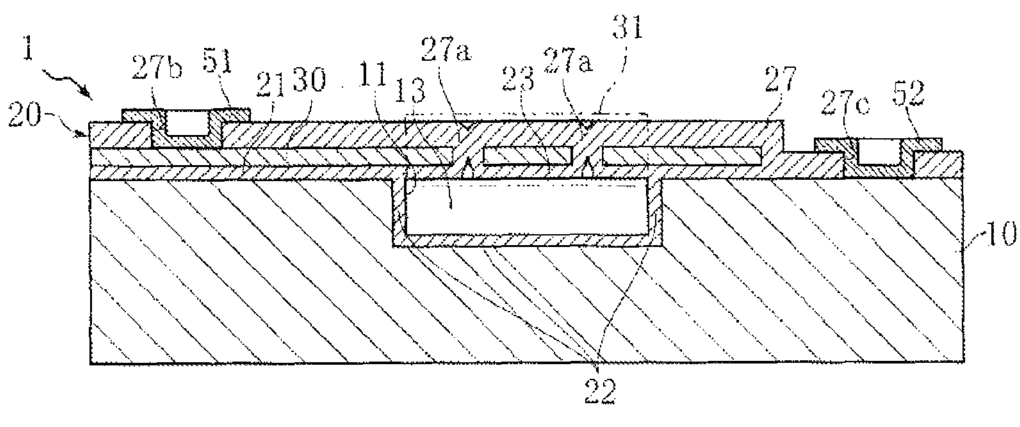

1
20
27b
51
21
30
11
13
27a
23
27a
31
27
27c
52
10
22

FIG.3

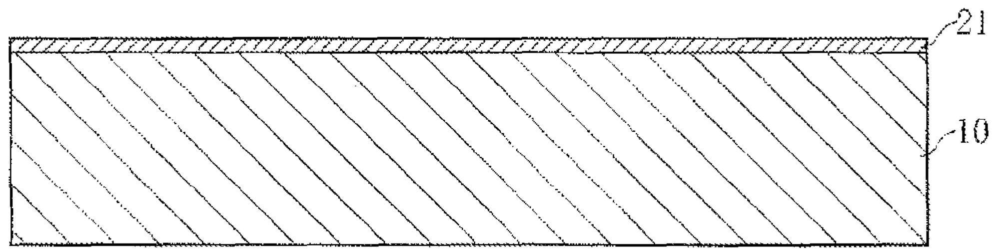


FIG.4

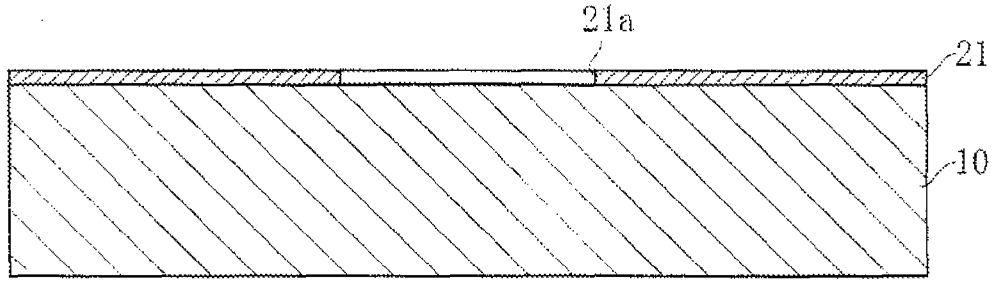


FIG.5

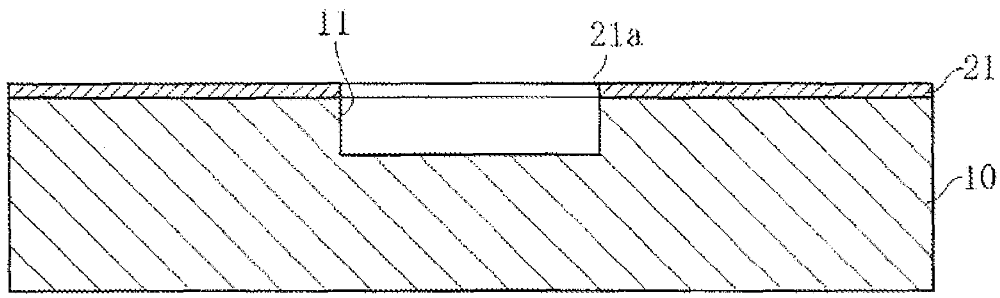


FIG.6

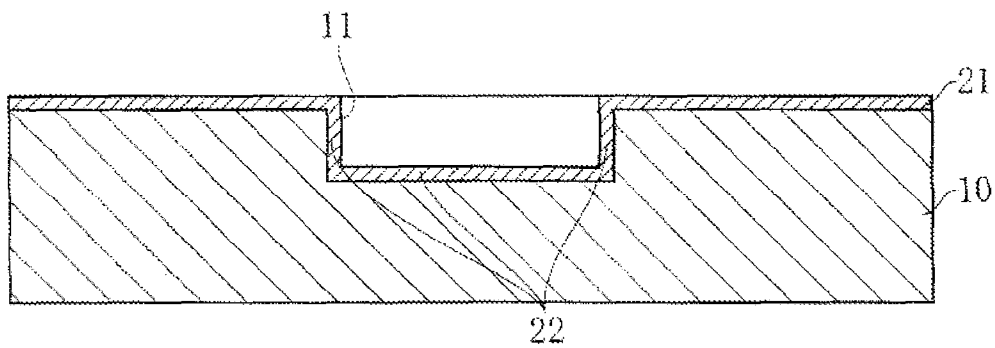


FIG.7

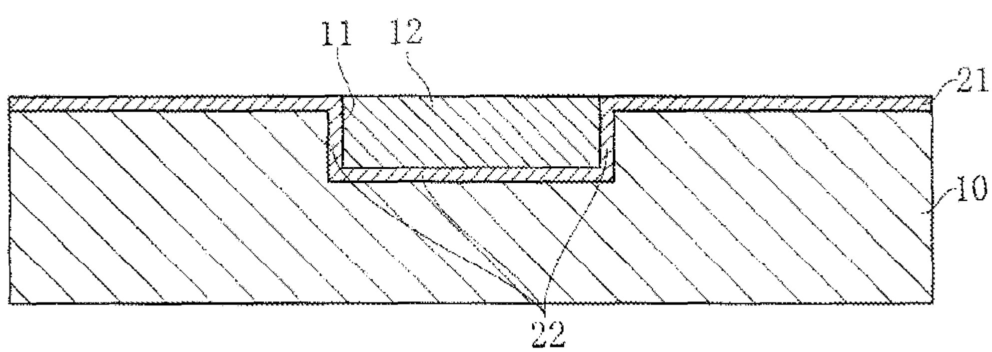


FIG.8

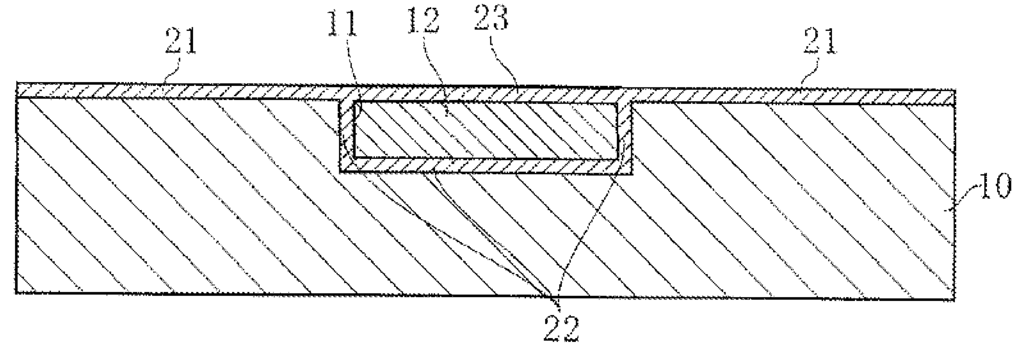


FIG.9

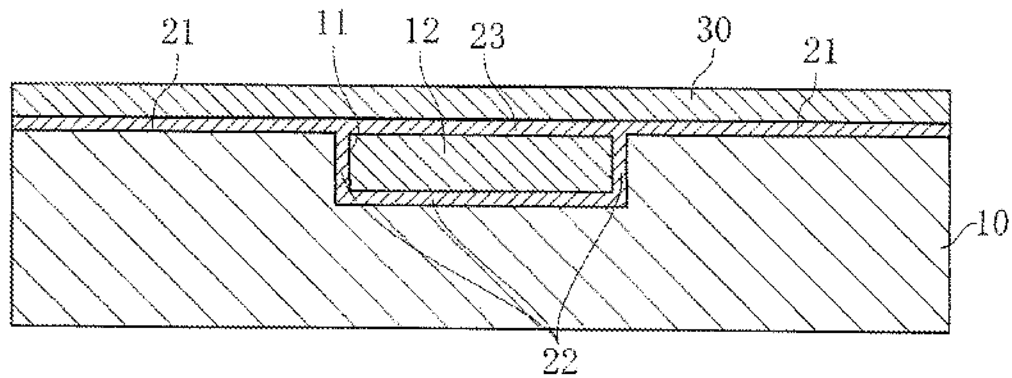


FIG.10

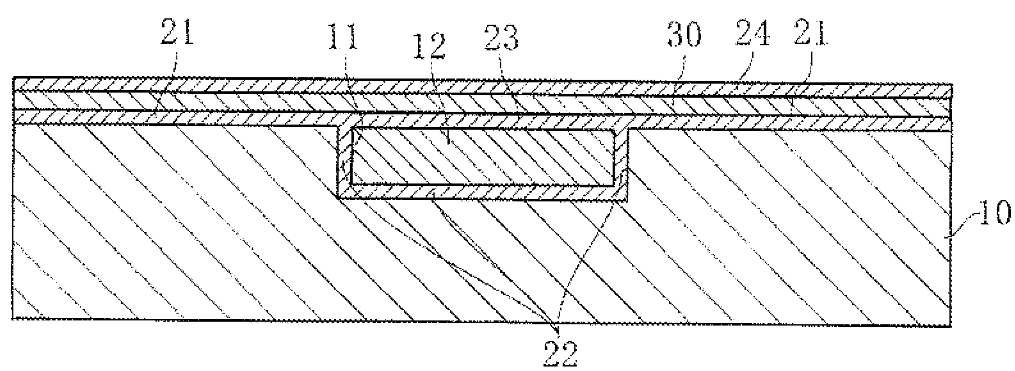


FIG.11

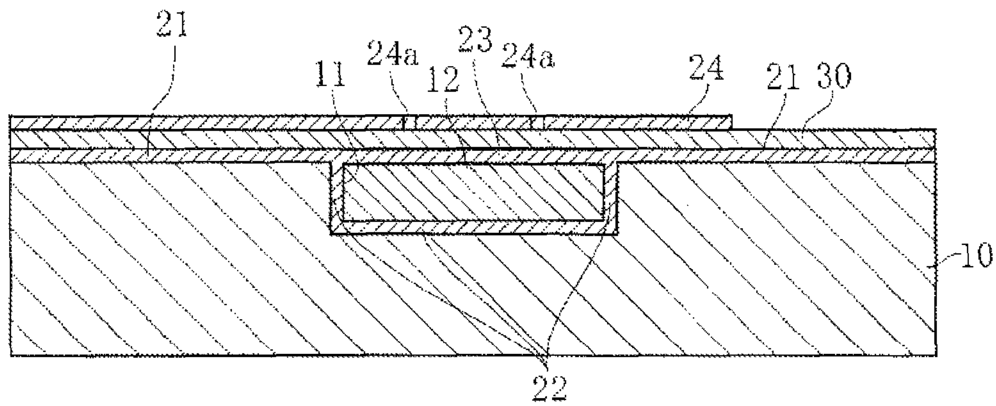


FIG.12

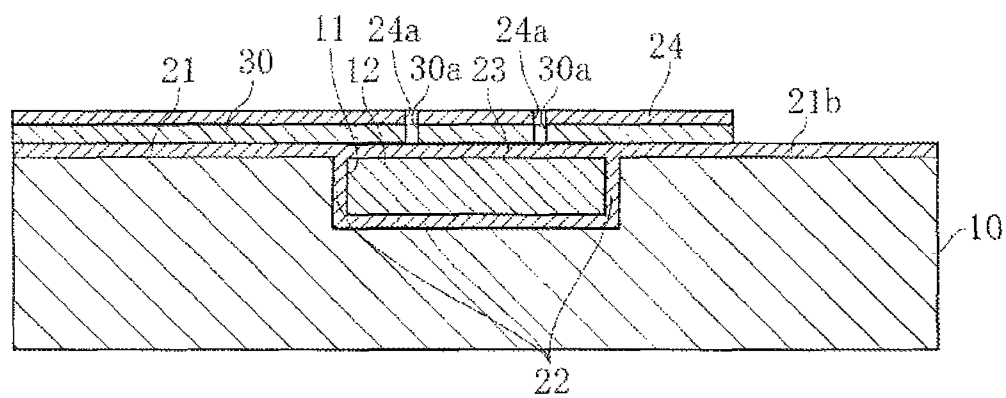


FIG.13

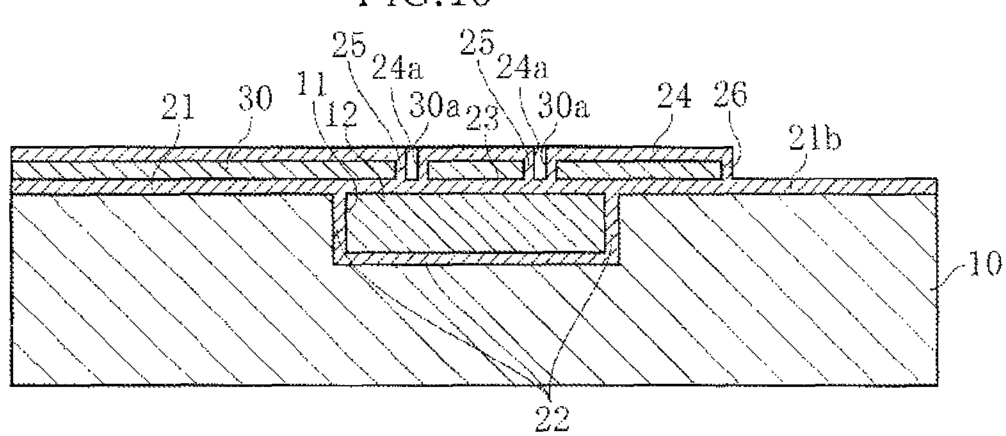


FIG.14

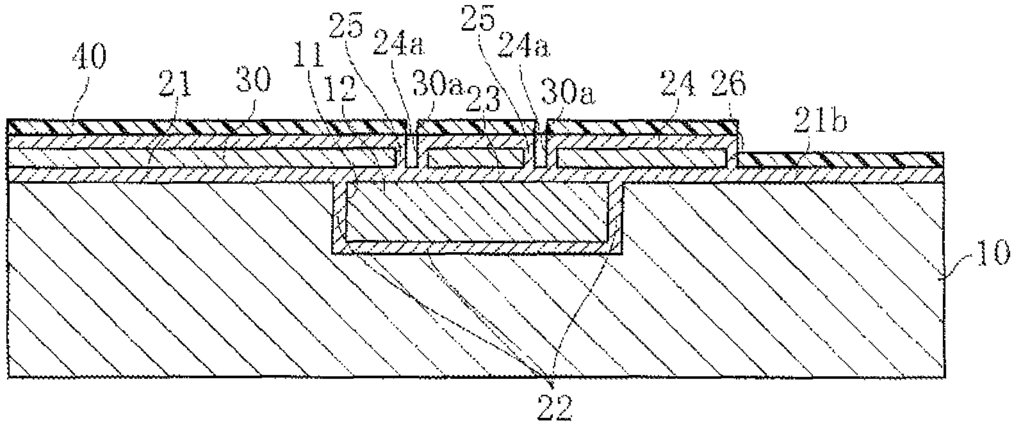


FIG.15

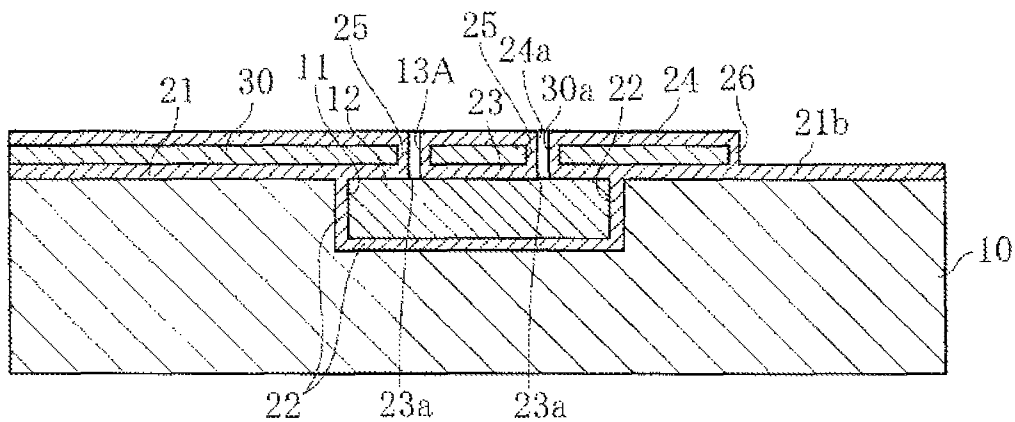


FIG.16

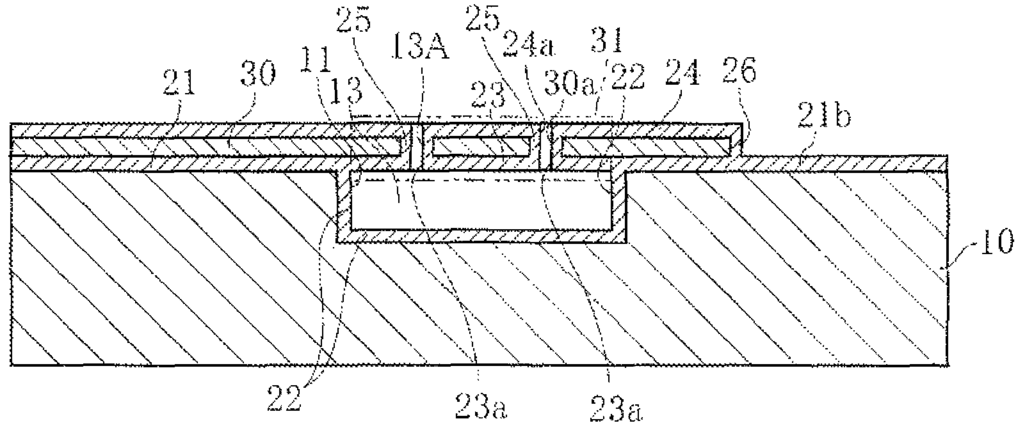


FIG.17

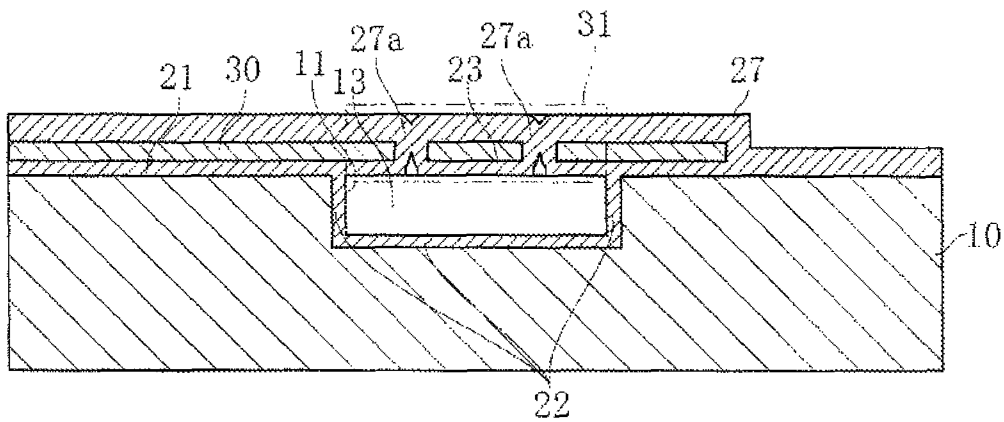

27a
27a
31
21
30
11
13
23
27
10
22

FIG.18

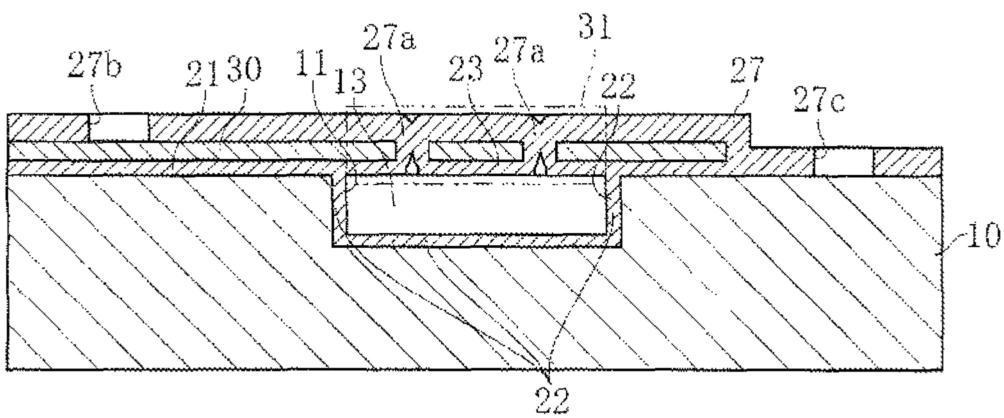

27b
21
30
11
13
27a
23
27a
31
22
27
27c
10
22

FIG.19

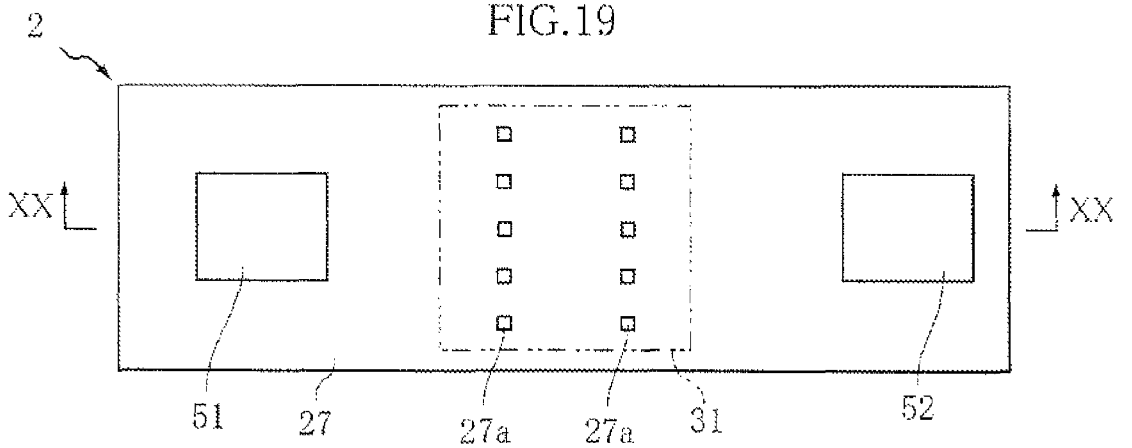

2
XX
XX
51
27
27a
27a
31
52

FIG.20

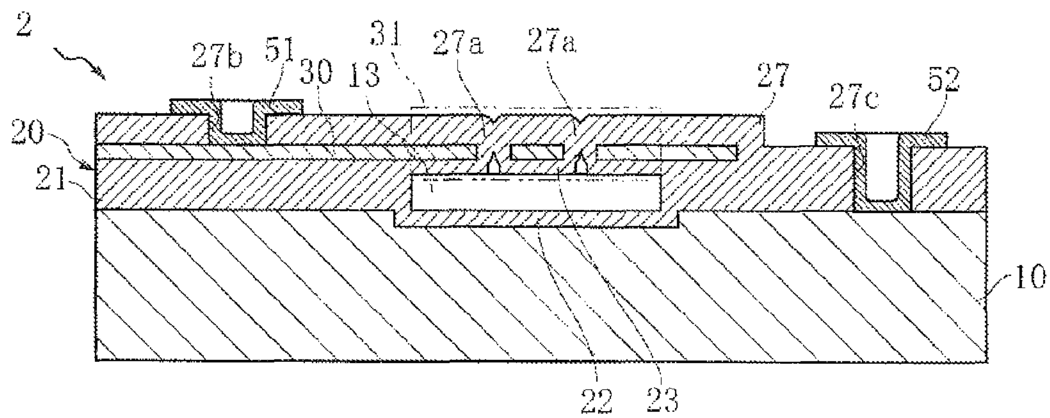

2
27b
51
30
13
31
27a
27a
27
27c
52
20
21
10
22
23

FIG.21

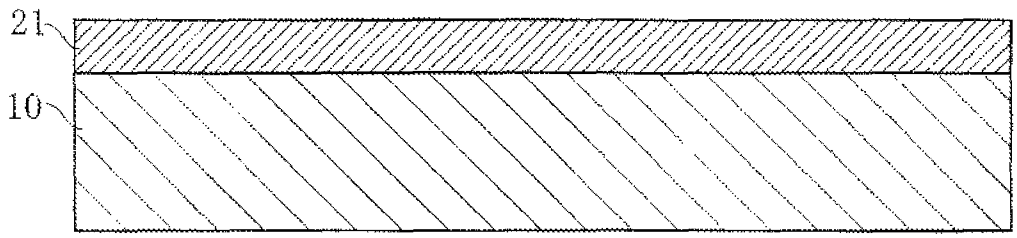


FIG.22

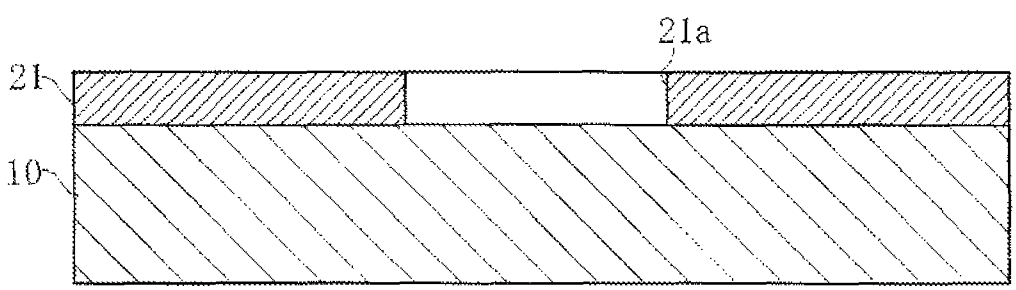


FIG.23

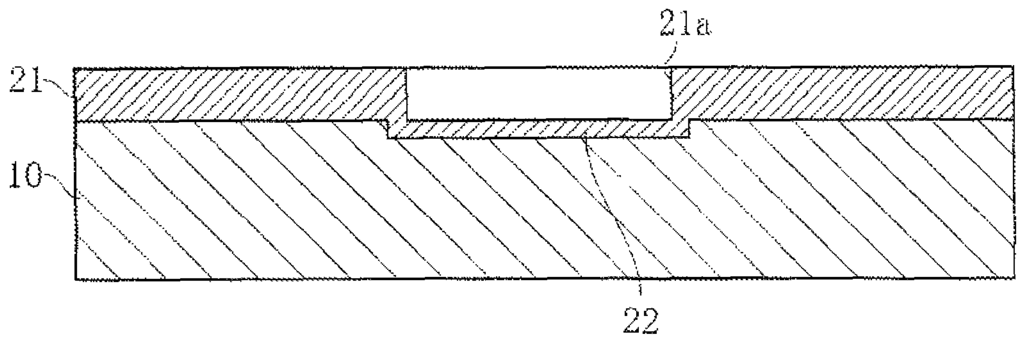


FIG.24

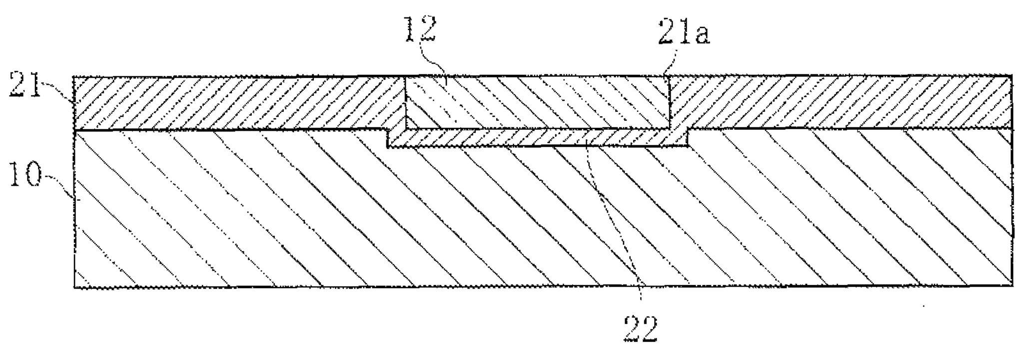


FIG.25

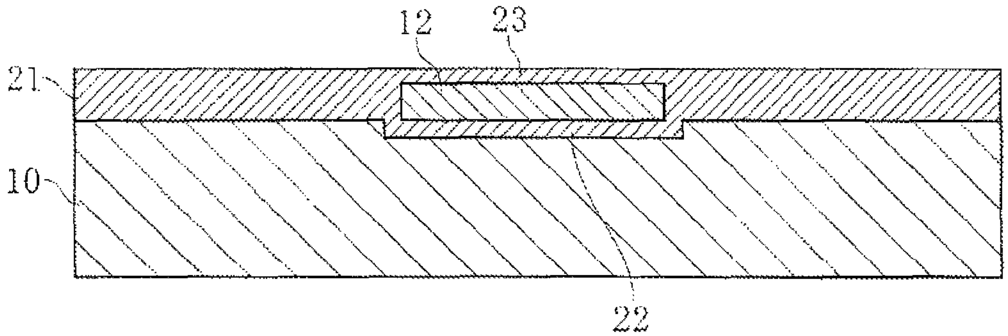


FIG.26

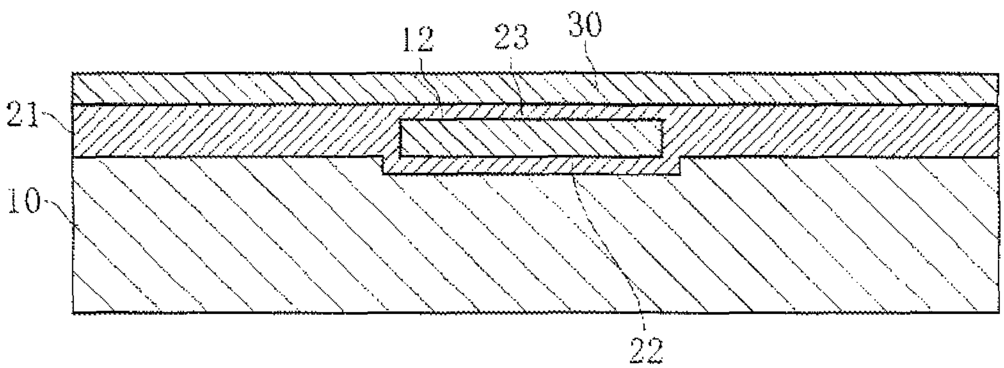


FIG.27

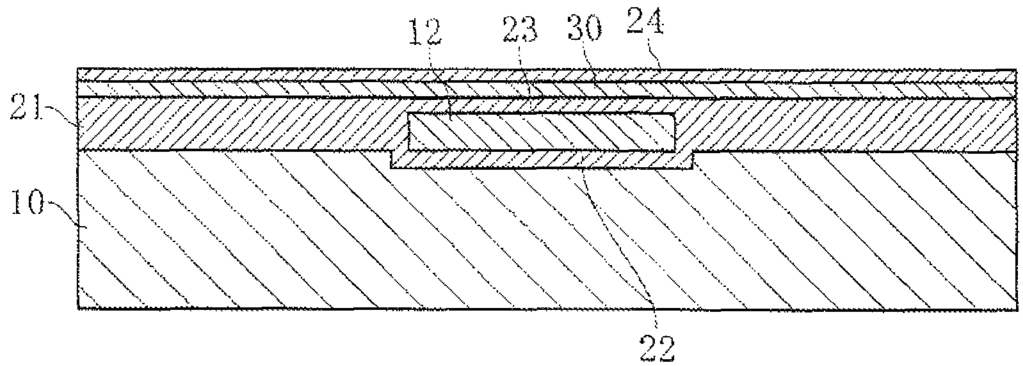


FIG.28

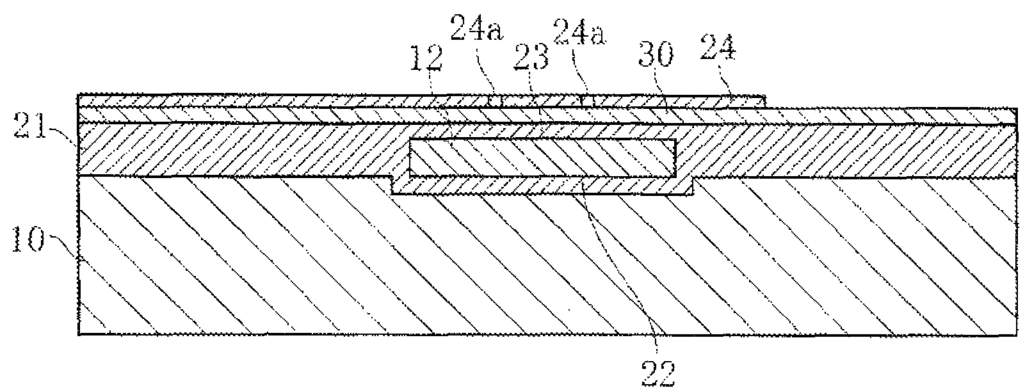


FIG.29

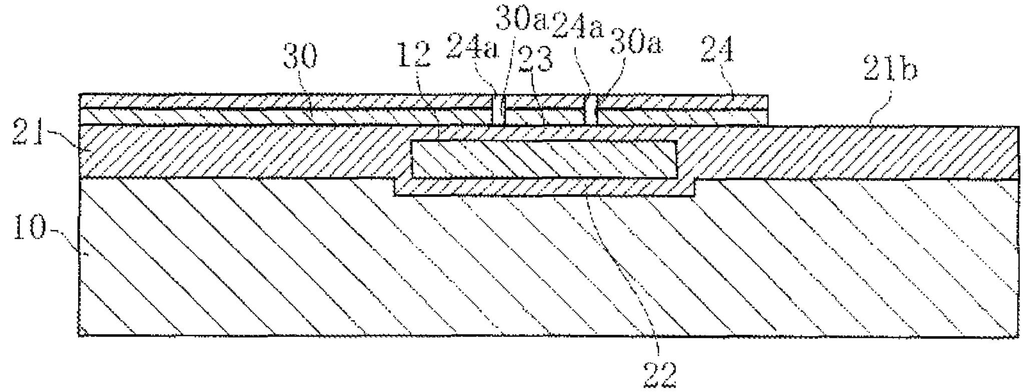


FIG.30

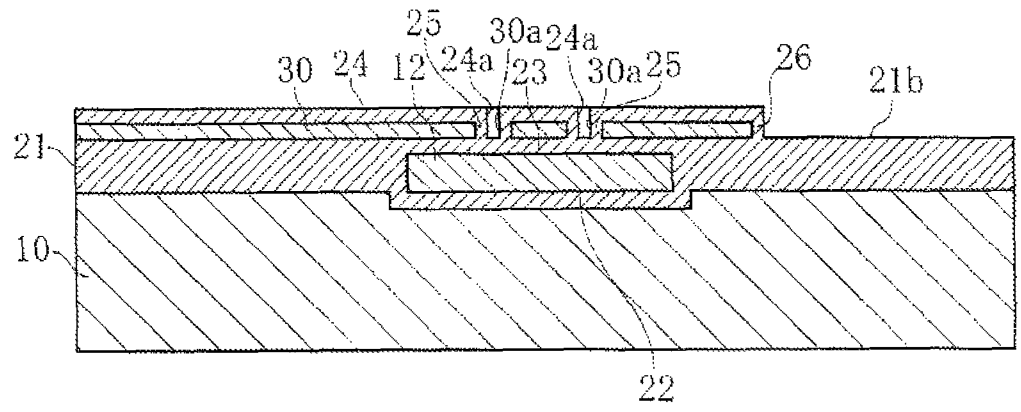


FIG.31

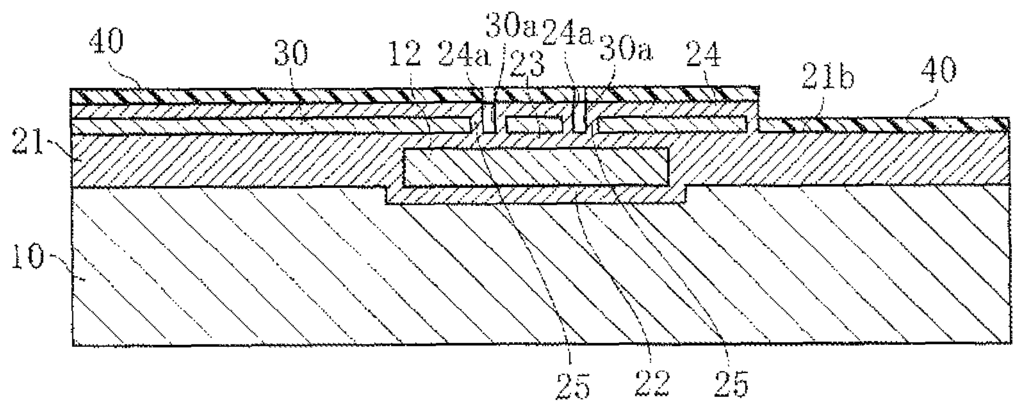


FIG.32

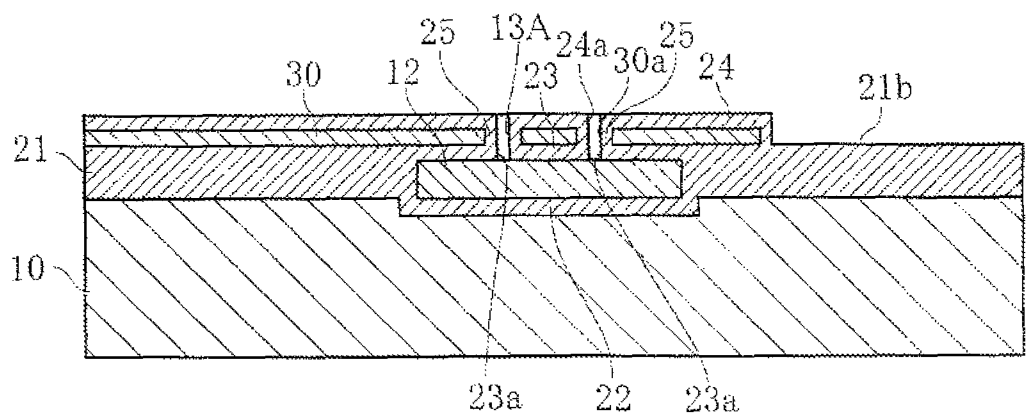


FIG.33

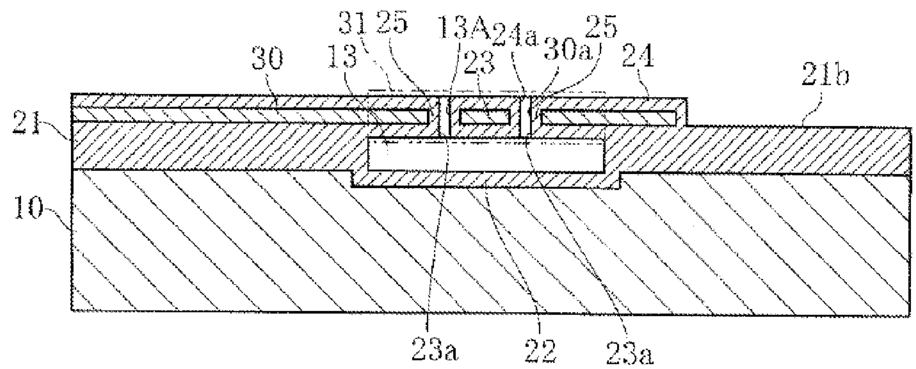


FIG.34

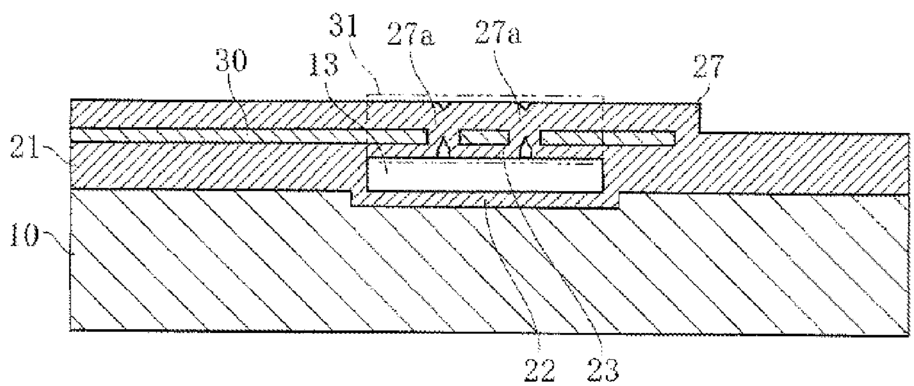


FIG.35

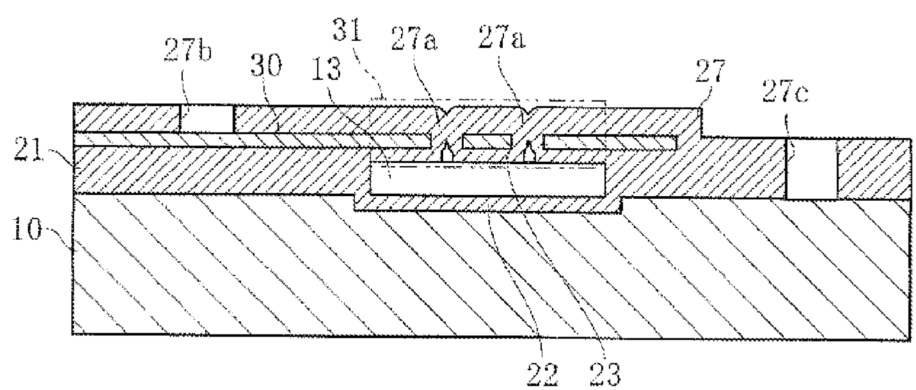


FIG.36

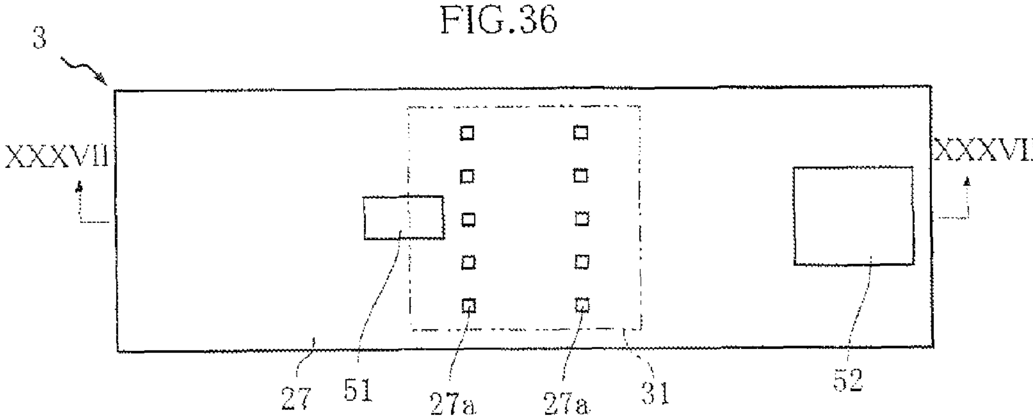

3
XXXVII
XXXVII
27
51
27a
27a
31
52

FIG.37

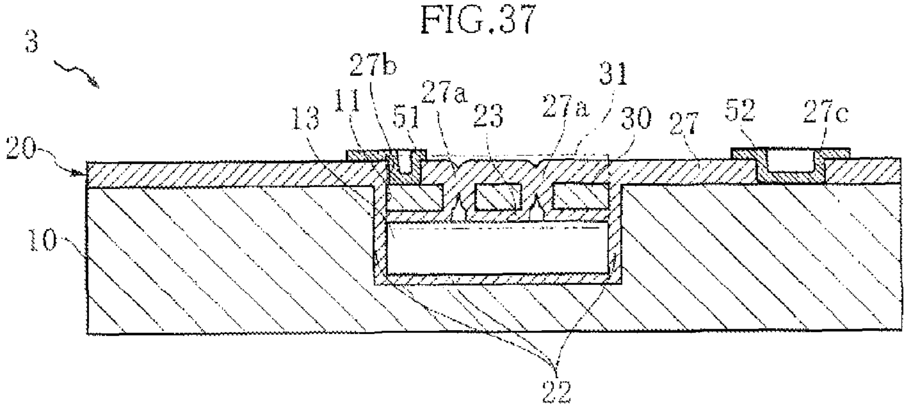

3
27b
31
27a
27a
13
11
51
23
30
27
52
27c
20
10
22

FIG.38

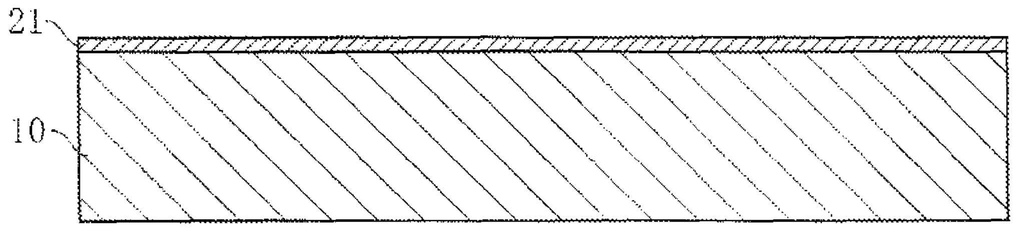


FIG.39

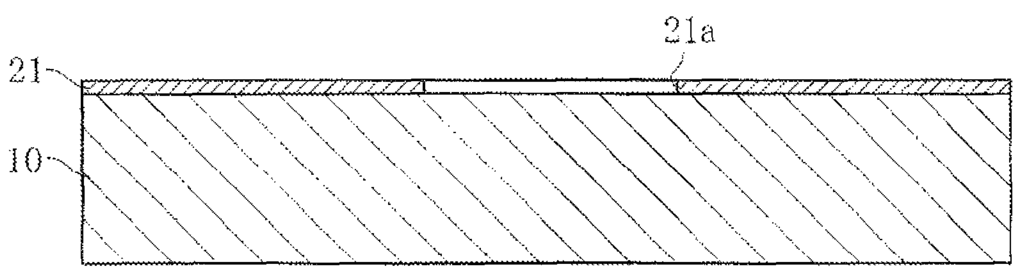


FIG.40

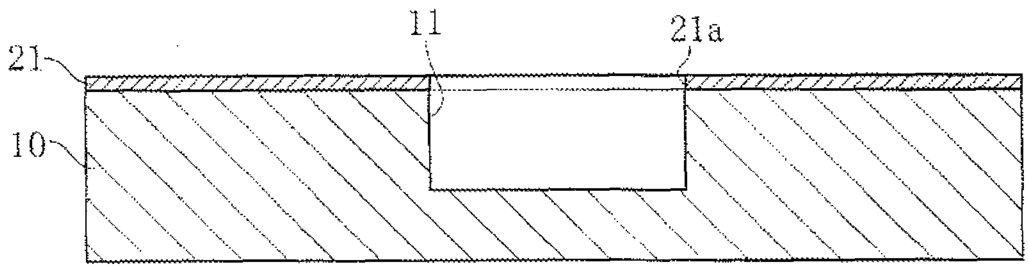


FIG.41

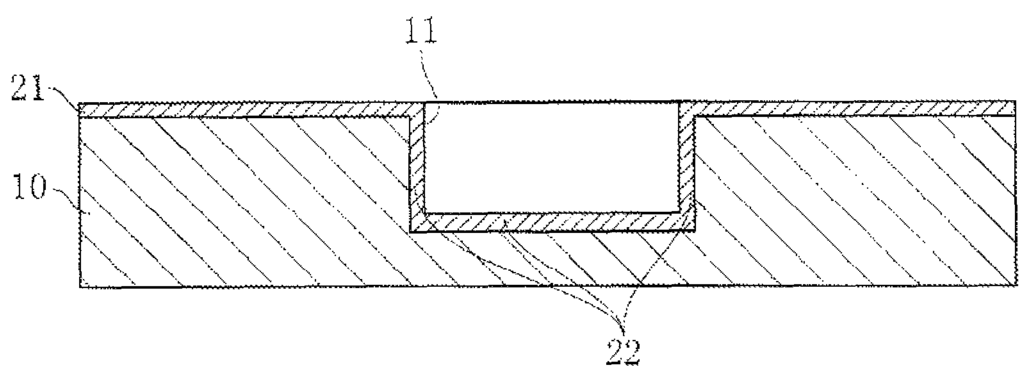


FIG.42

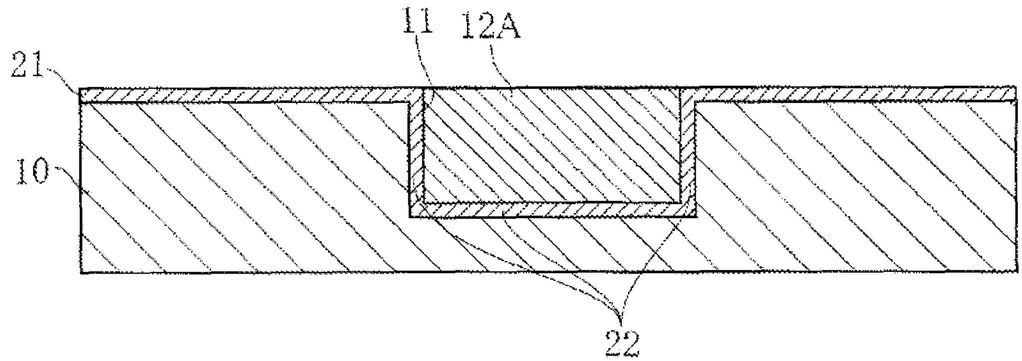


FIG.43

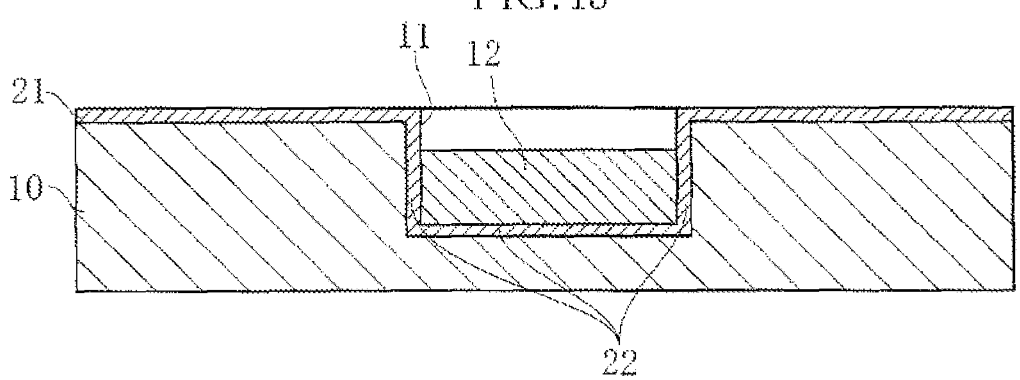


FIG.44

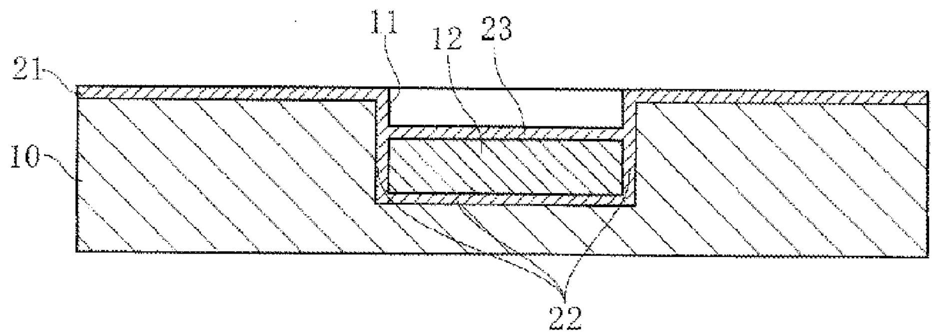


FIG.45

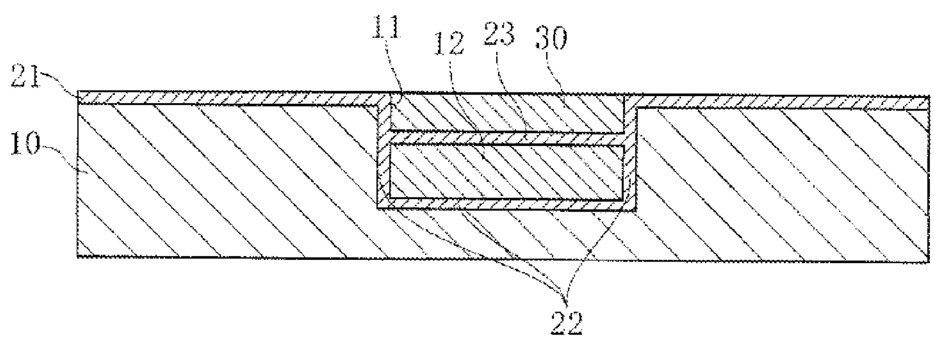


FIG.46

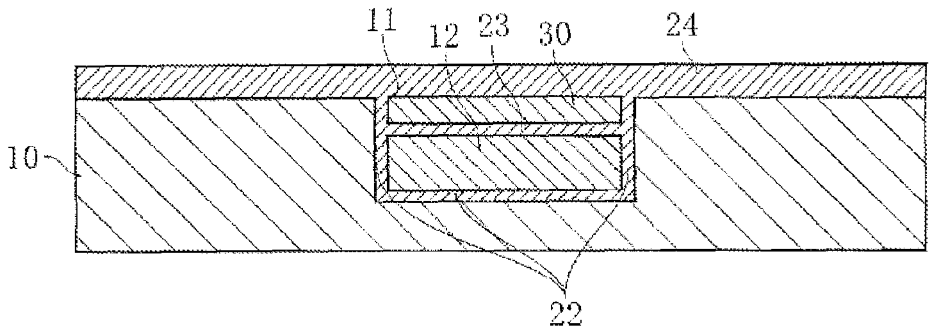


FIG.47

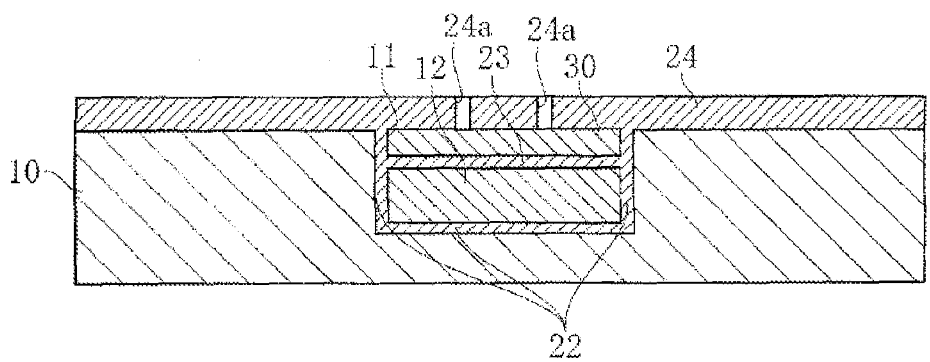


FIG.48

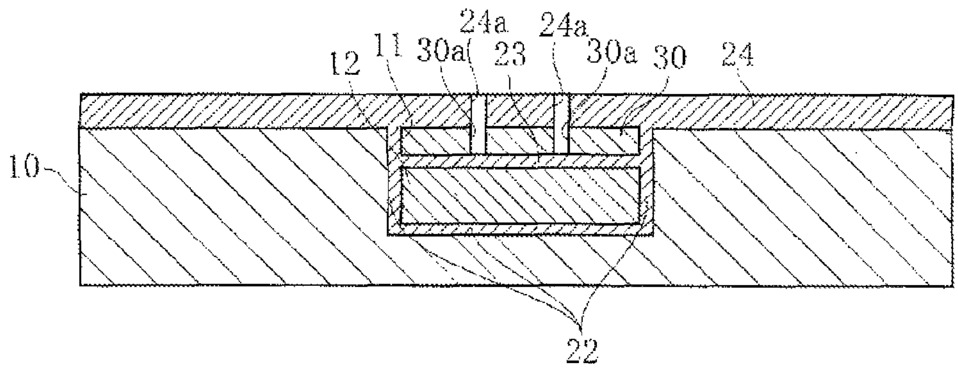

24a
24a
12
11
30a
23
30a
30
24
10
22

FIG.49

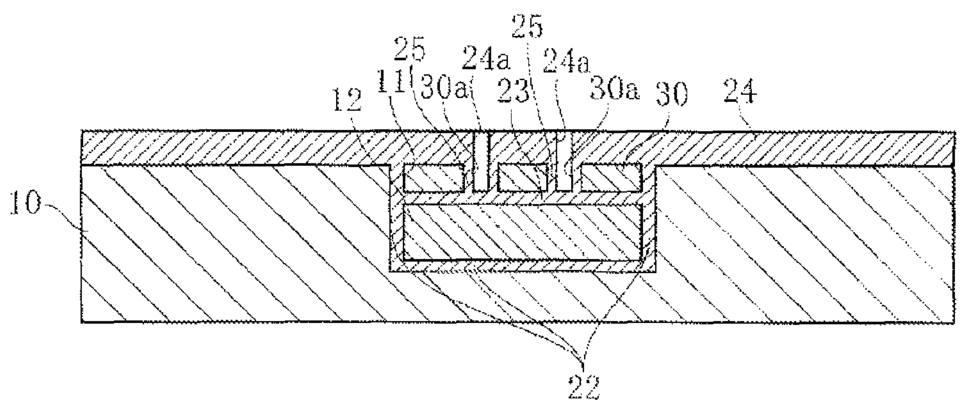

25
25
24a
24a
12
11
30a
23
30a
30
24
10
22

FIG.50

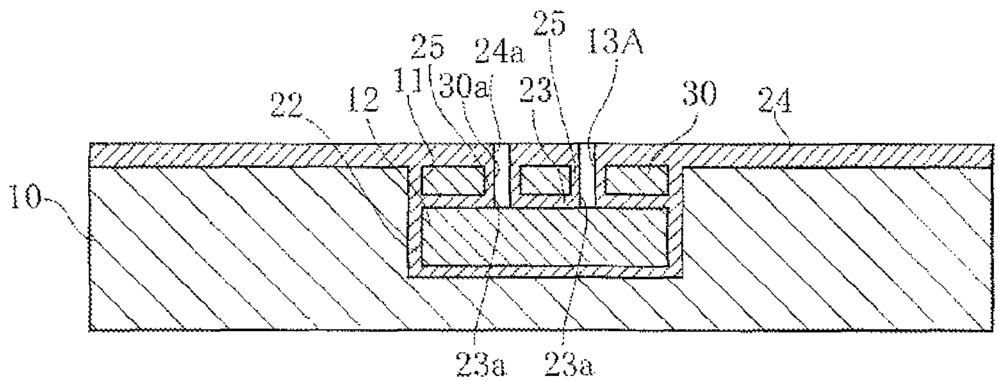

25
24a
25
13A
11
30a
23
30
22
12
24
10
23a
23a

FIG.51

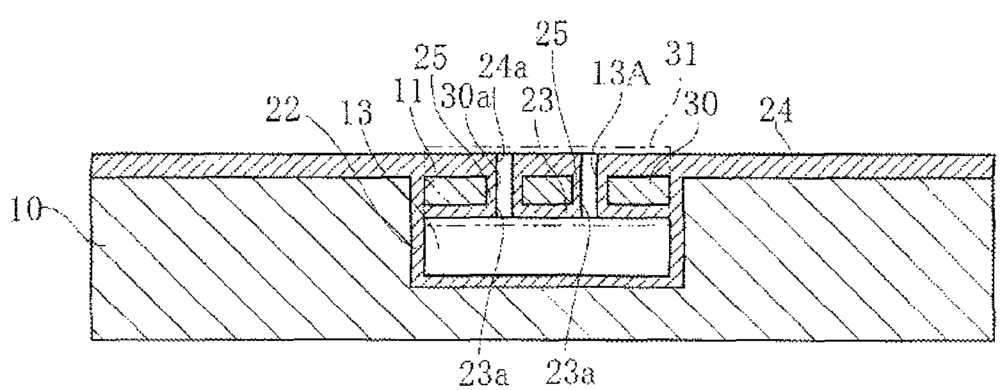
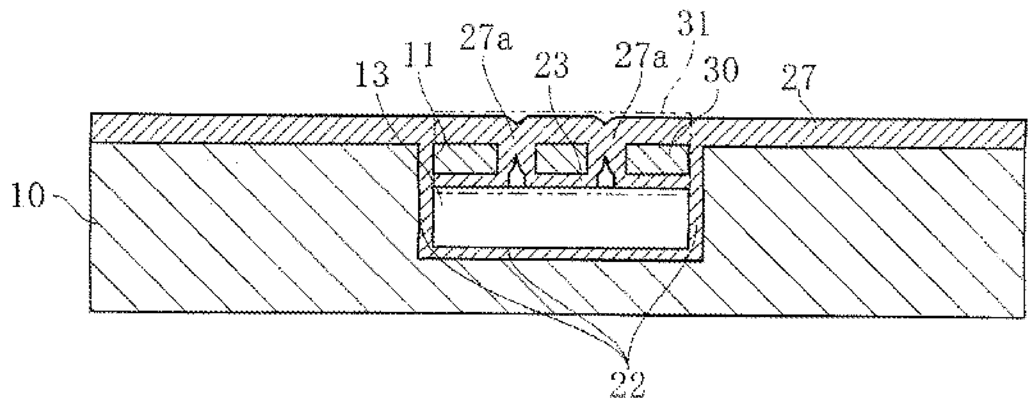
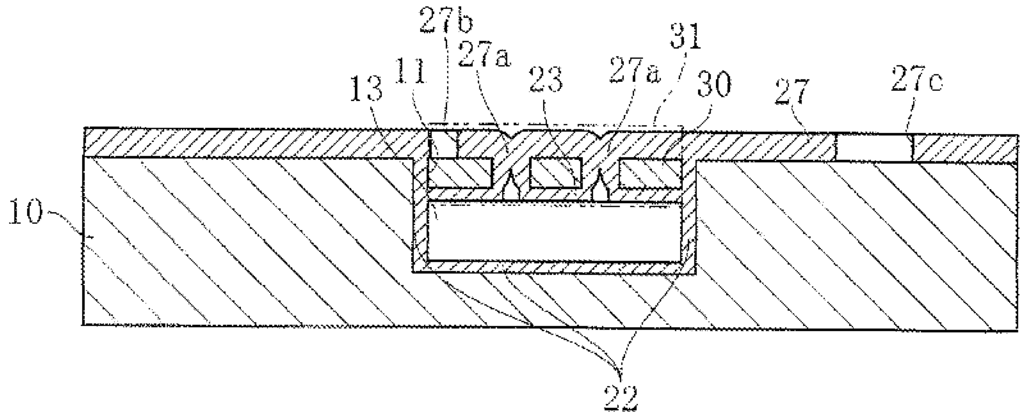

25
25
24a
13A
31
11
30a
23
30
22
13
24
10
23a
23a

FIG.52



27a
11
23
27a
31
30
13
27
10
22

FIG.53



27b
27a
11
23
27a
31
30
13
27
27c
10
22

FIG.54

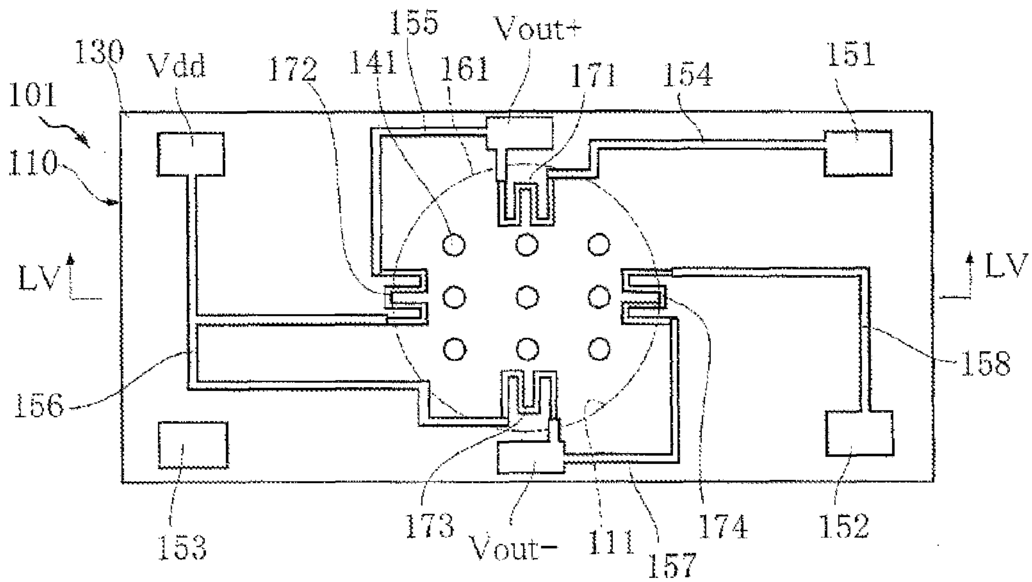

155
Vout+
130
Vdd
172
141
161
171
154
151
101
110
LV
LV
158
156
173
Vout-
111
174
152
153
157

FIG.55

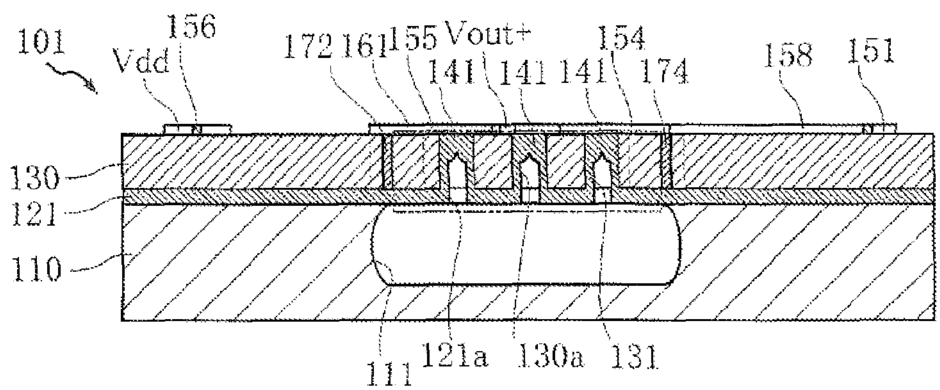

101
Vdd
156
172
161
155
Vout+
141
141
141
154
174
158
151
130
121
110
111
121a
130a
131

FIG.56

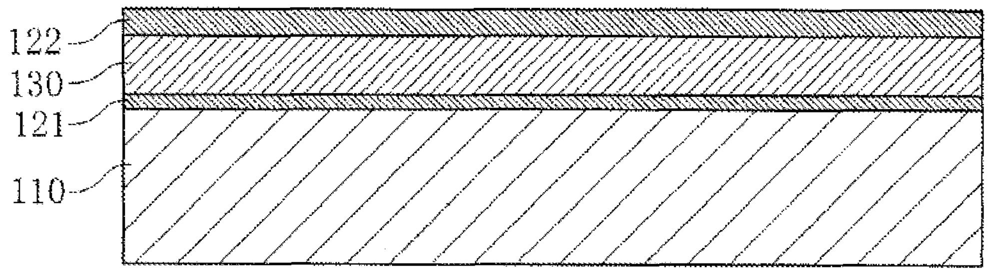


FIG.57

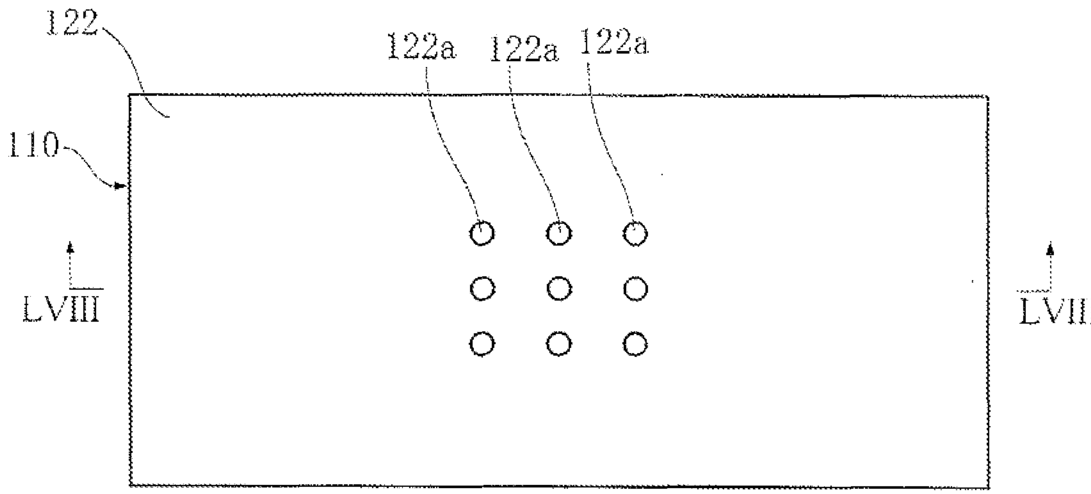


FIG.58

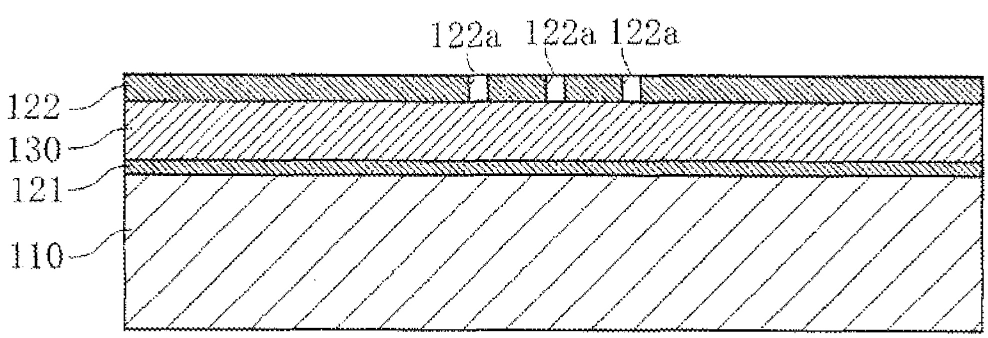


FIG.59

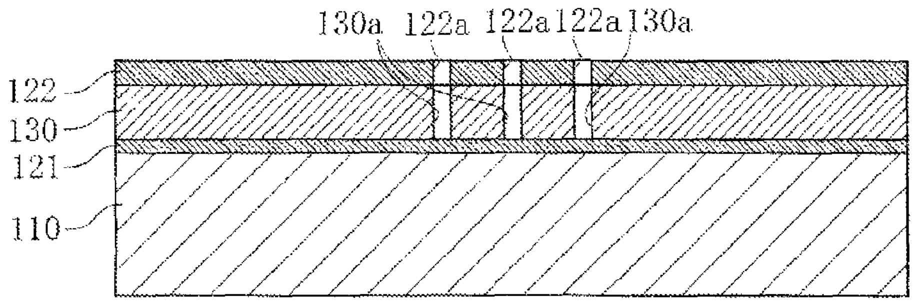


FIG.60

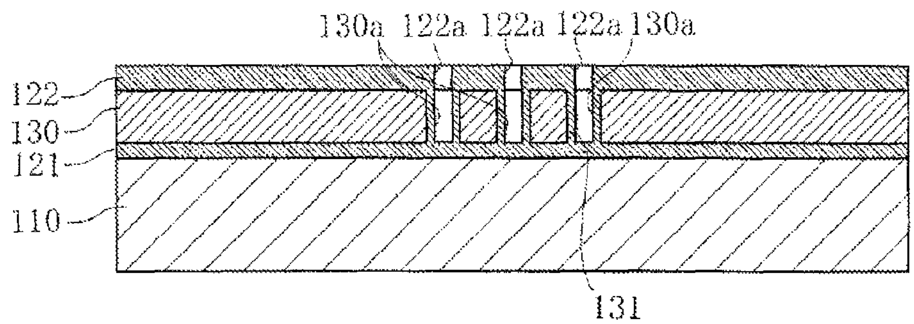


FIG.61

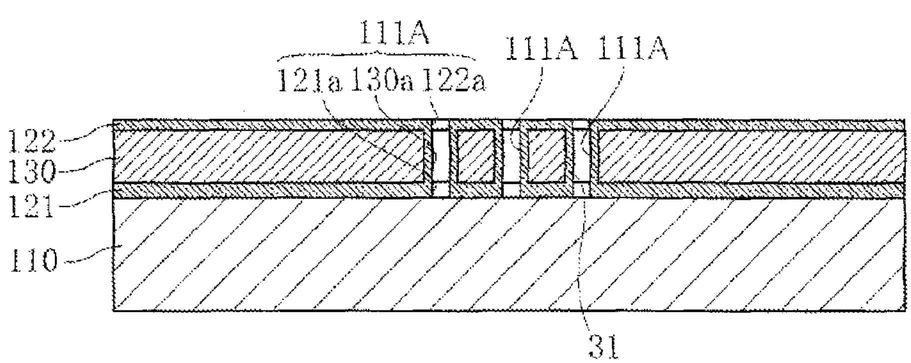


FIG.62

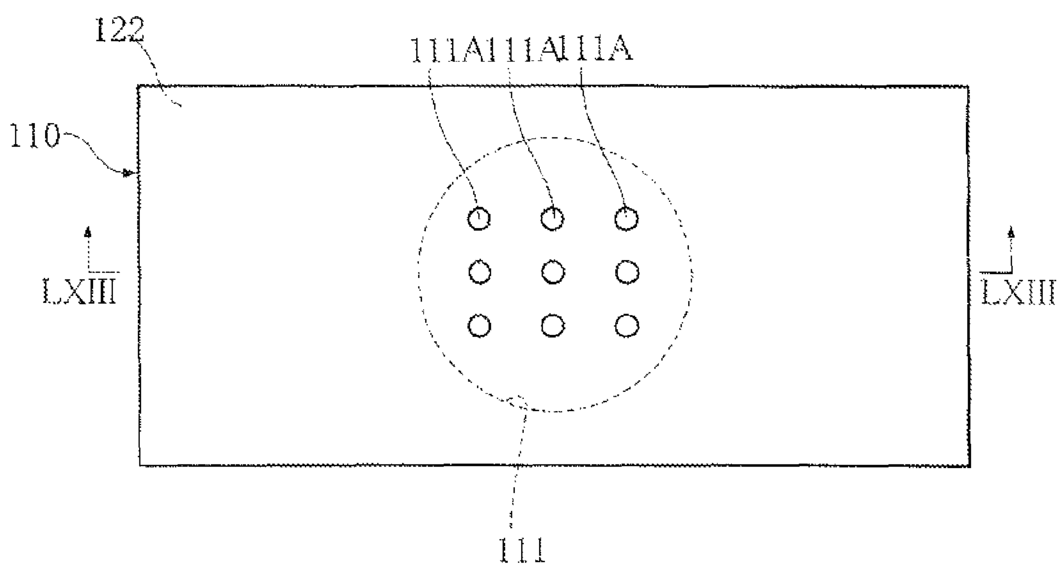


FIG.63

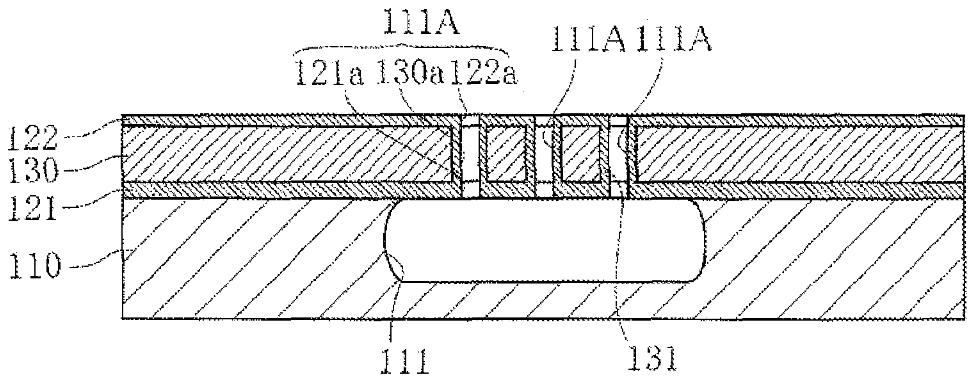

111A
121a 130a 122a
111A 111A
122
130
121
110
111
131

FIG.64

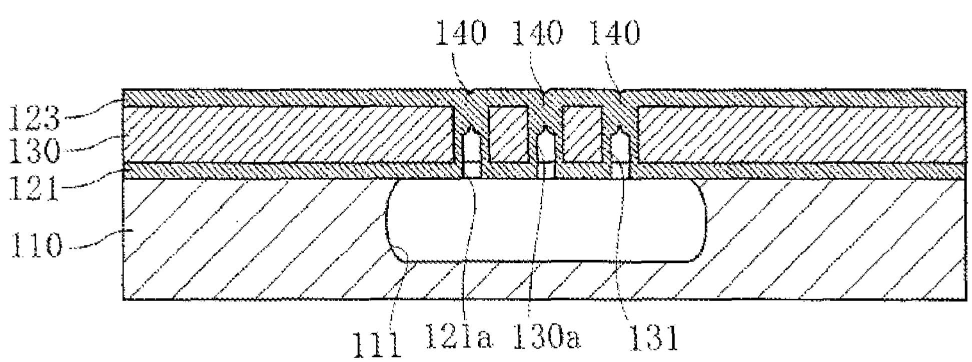

140 140 140
123
130
121
110
111
121a 130a
131

FIG.65

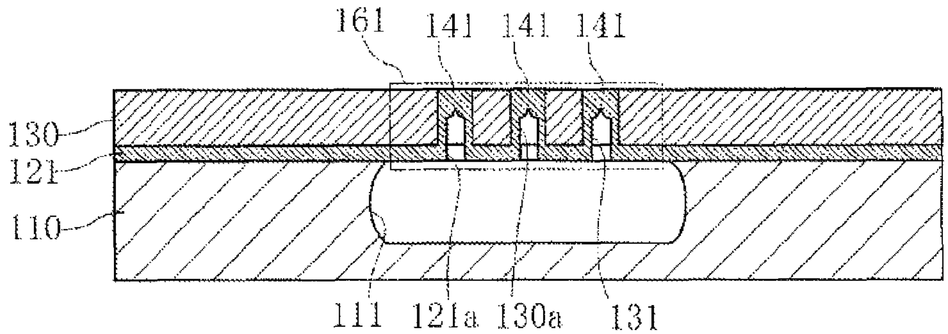


FIG.66

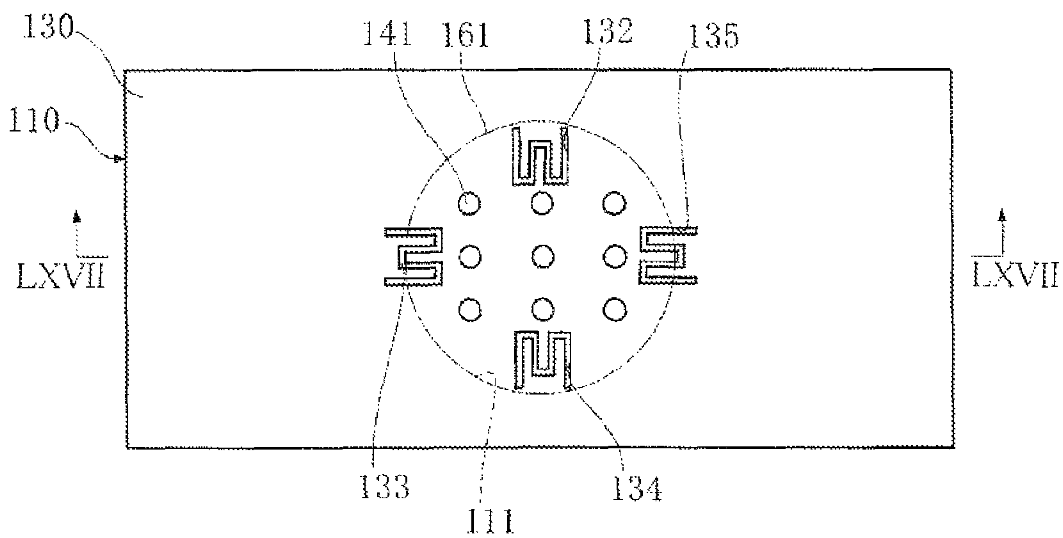


FIG.67

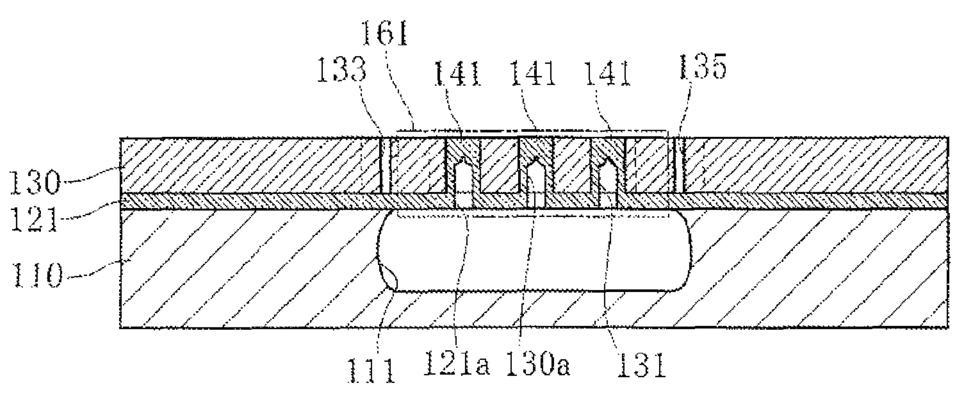


FIG.68

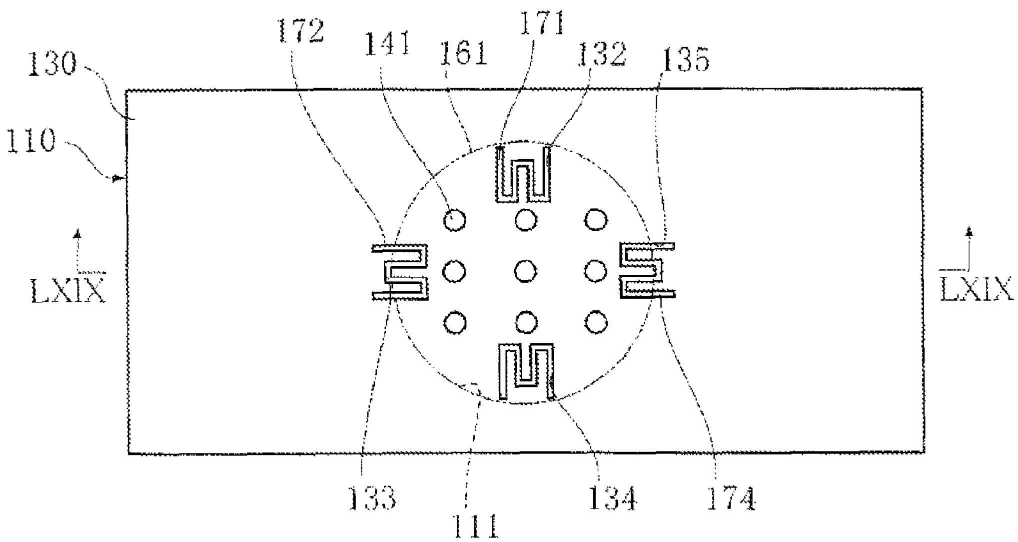

172
141
161
171
132
135
130
110
LXIX
LXIX
133
111
134
174

FIG.69

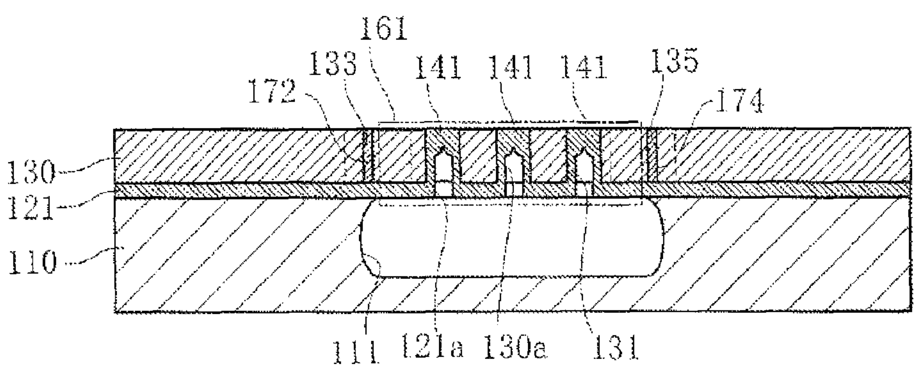

161
133
141
141
141
135
172
174
130
121
110
111
121a
130a
131

FIG.70

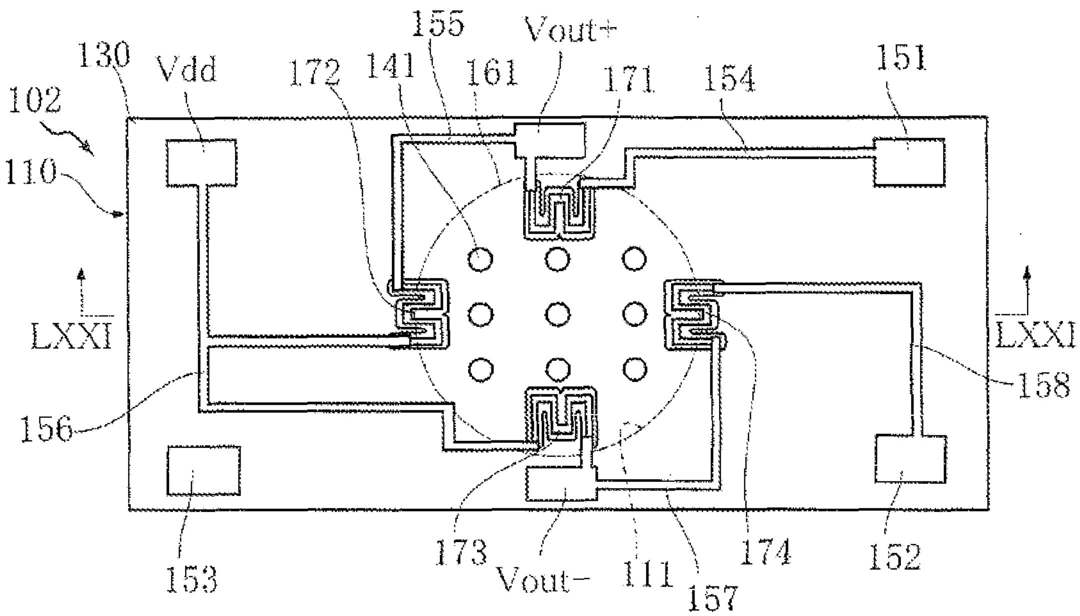

155
Vout+
130
Vdd
172
141
161
171
154
151
102
110
LXXI
LXXI
158
156
153
173
Vout-
111
157
174
152

FIG.71

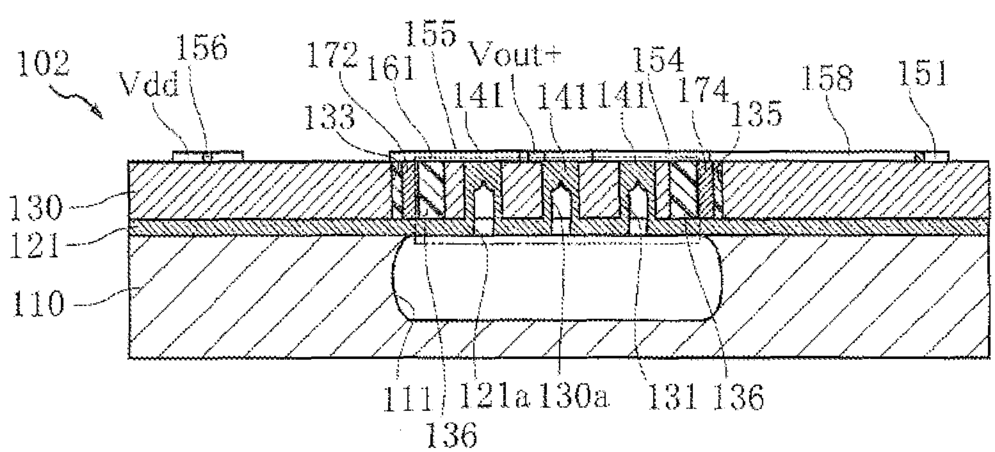

155
Vout+
102
156
172
161
154
151
Vdd
141
141
141
174
158
133
135
130
121
110
111
136
121a
130a
131
136
136

FIG.72

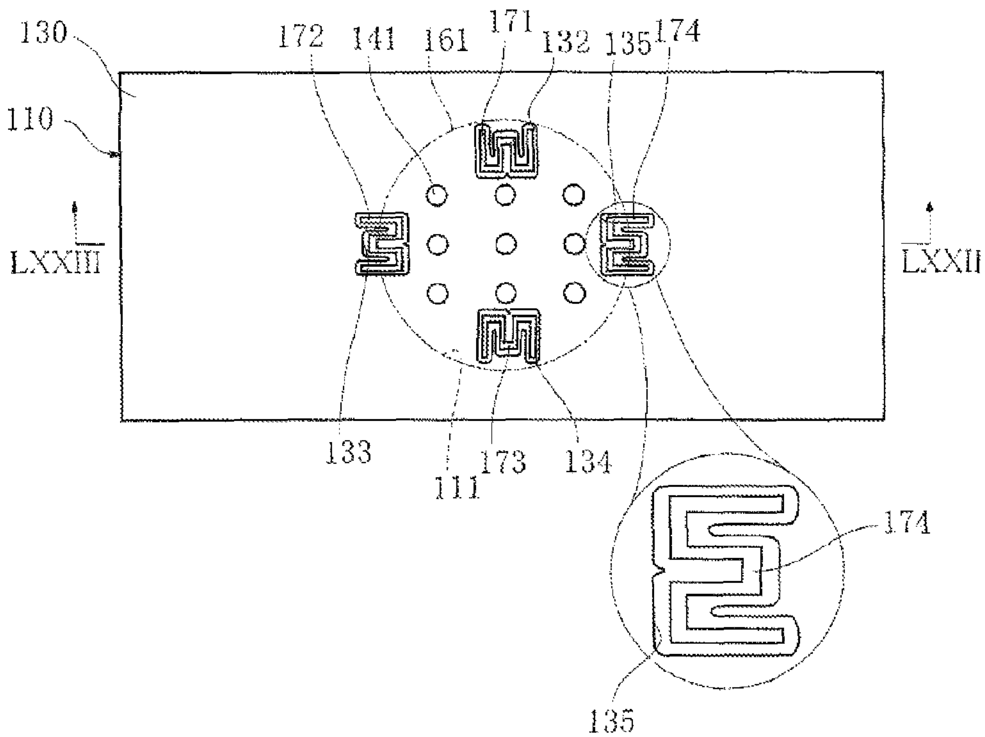

130
110
172
141
161
171
132
135
174
LXXIII
LXXIII
133
111
173
134
174
135

FIG.73

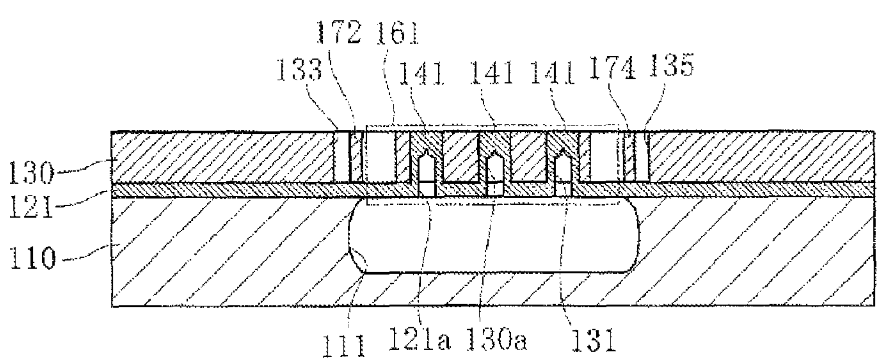

172
161
133
141
141
141
174
135
130
121
110
111
121a
130a
131

FIG.74

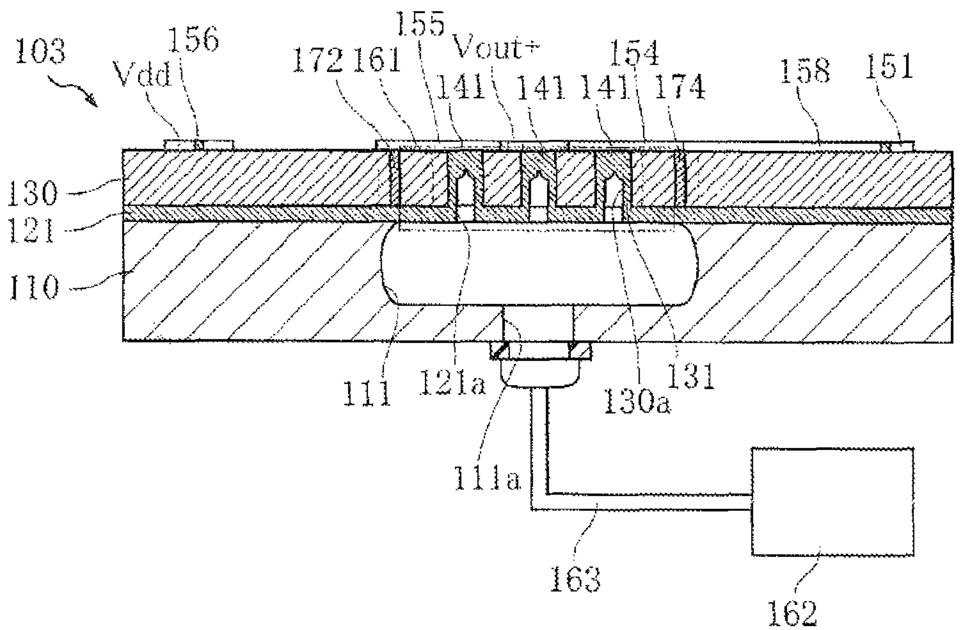

103
Vdd
156
172
161
155
Vout+
141
141
141
154
174
158
151
130
121
110
111
121a
130a
131
111a
163
162

FIG.75

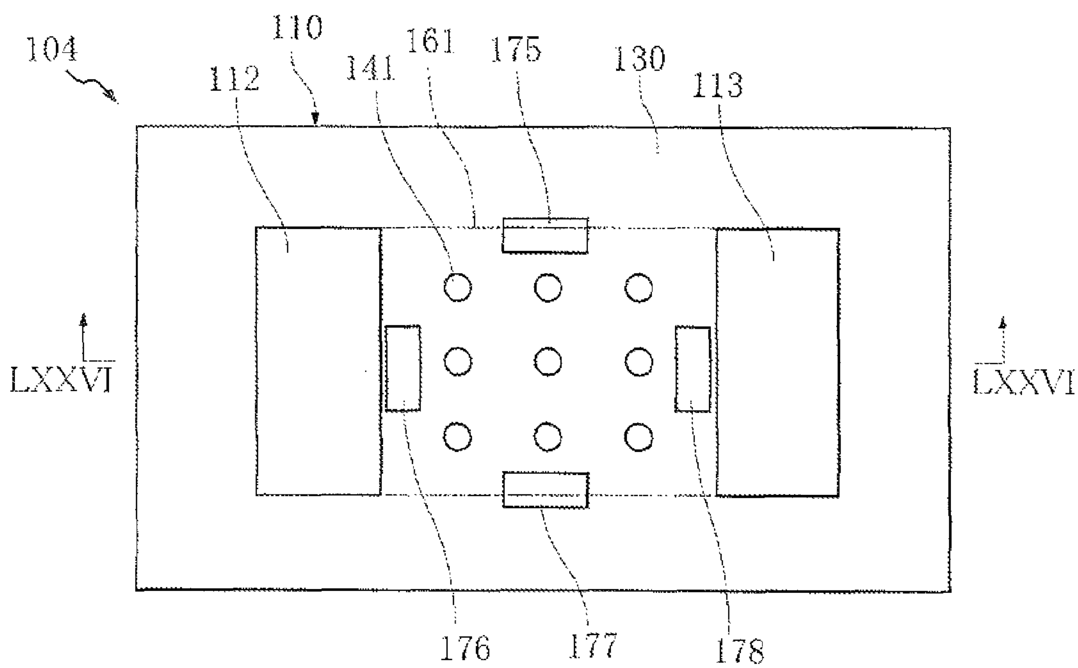

104
110
112
141
161
175
130
113
LXXVI
LXXVI
176
177
178

FIG.76

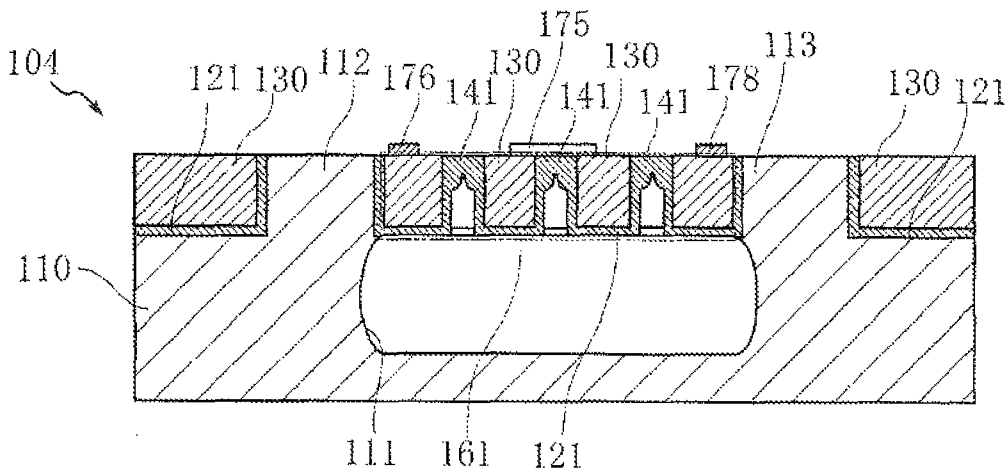

104
121
130
112
176
141
130
175
141
130
141
178
113
130
121
110
111
161
121

FIG.77

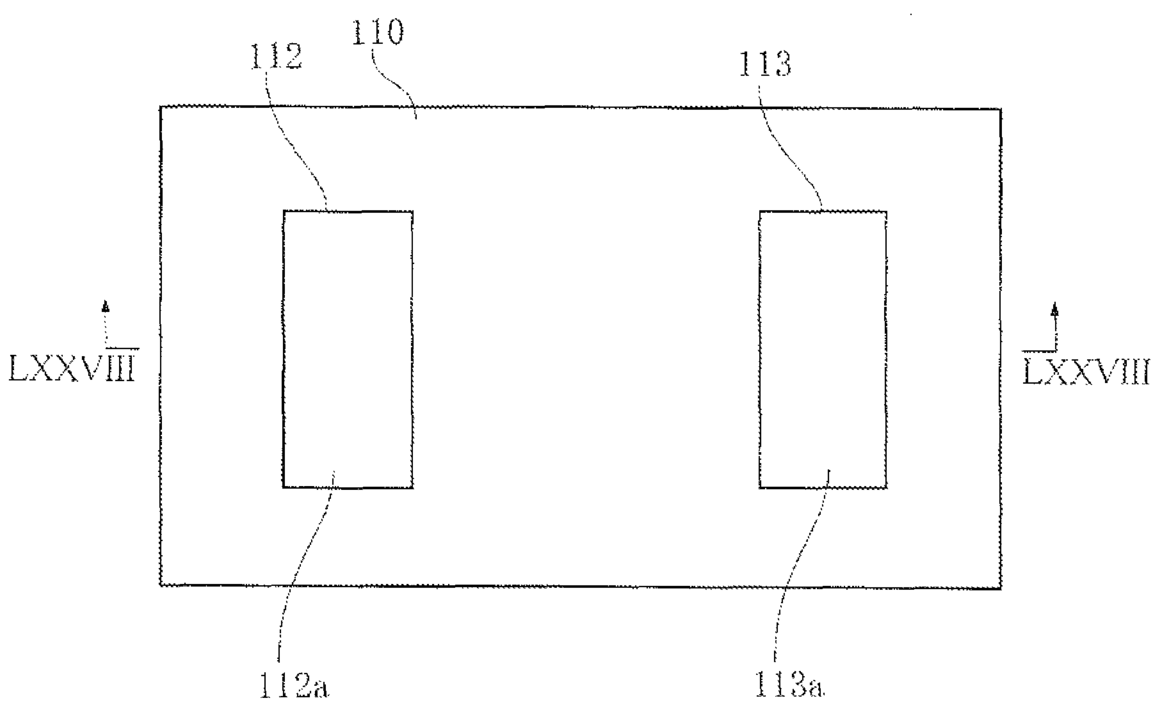

112
110
113
LXXVIII
LXXVIII
112a
113a

FIG.78

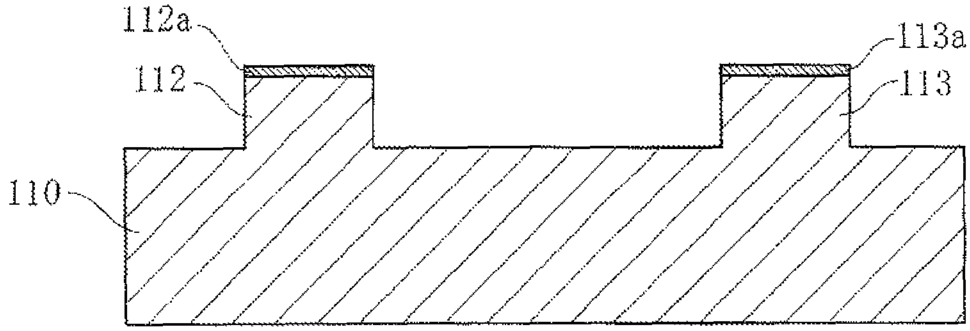


FIG.79

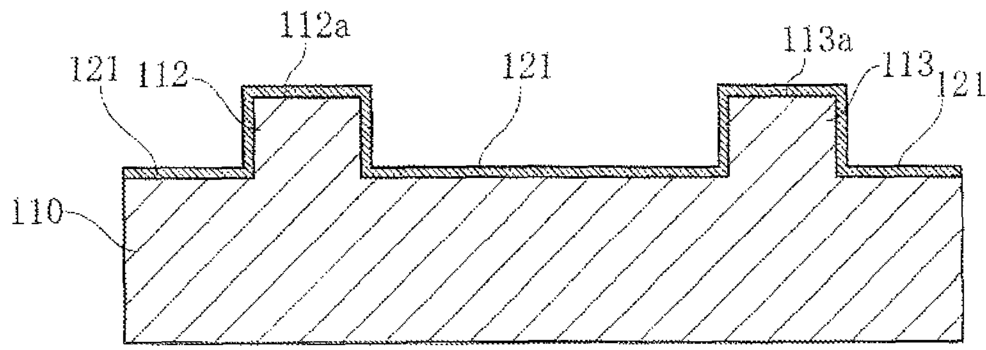


FIG.80

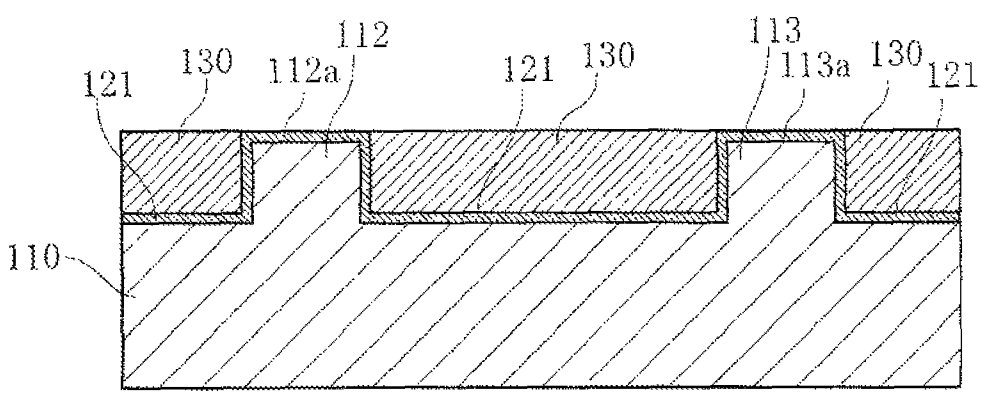


FIG.81

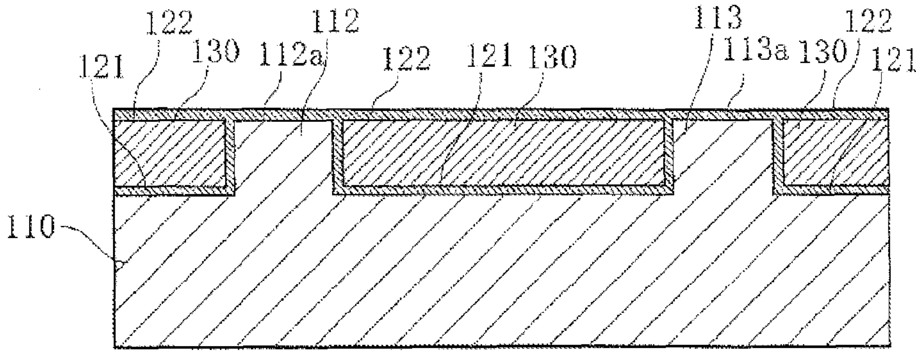


FIG.82

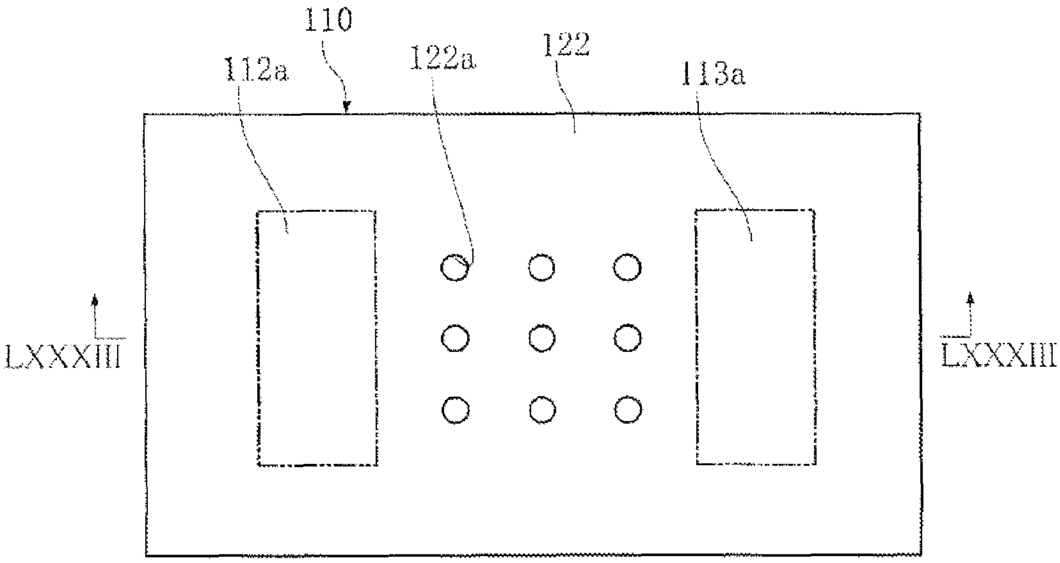


FIG.83

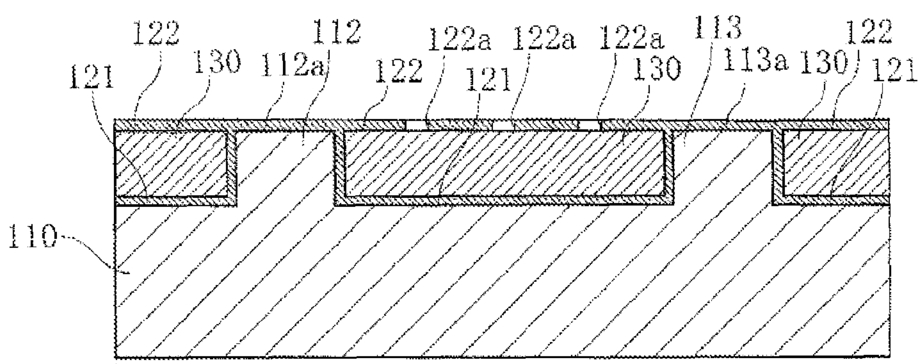


FIG.84

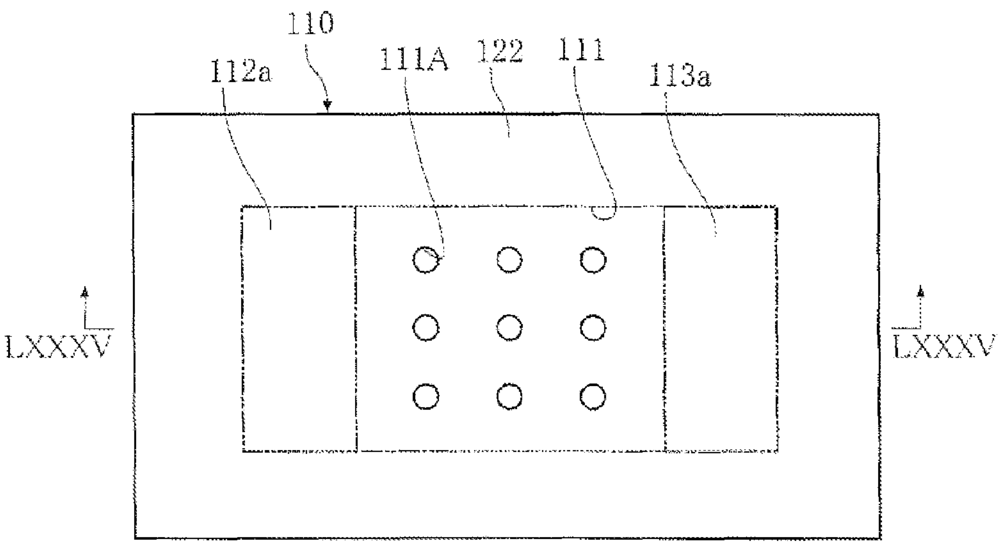

110
112a
111A
122
111
113a
LXXXV
LXXXV

FIG.85

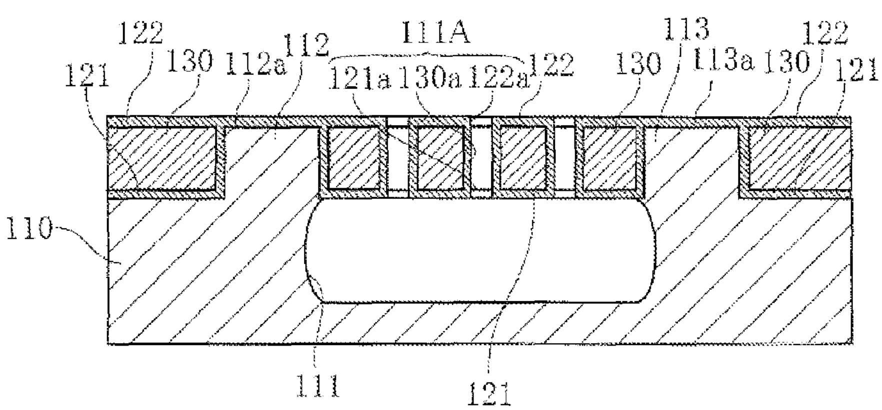

122
121
130
112a
112
111A
121a
130a
122a
122
130
113
113a
130
122
121
110
111
121

FIG.86

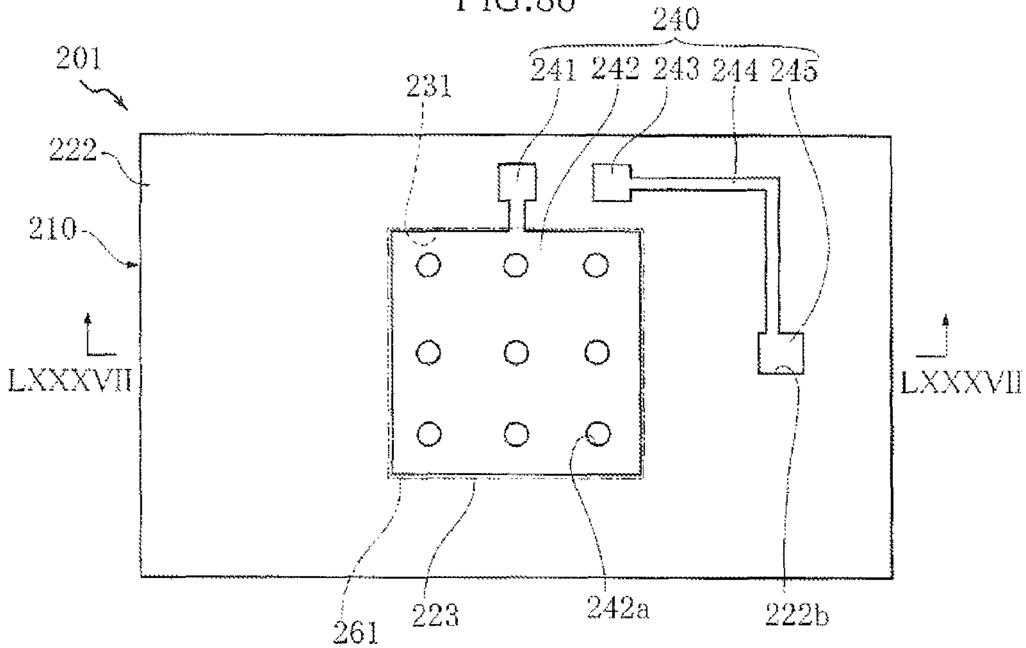

240
201
231
241 242 243 244 245
222
210
LXXXVII
LXXXVII
261
223
242a
222b

FIG.87

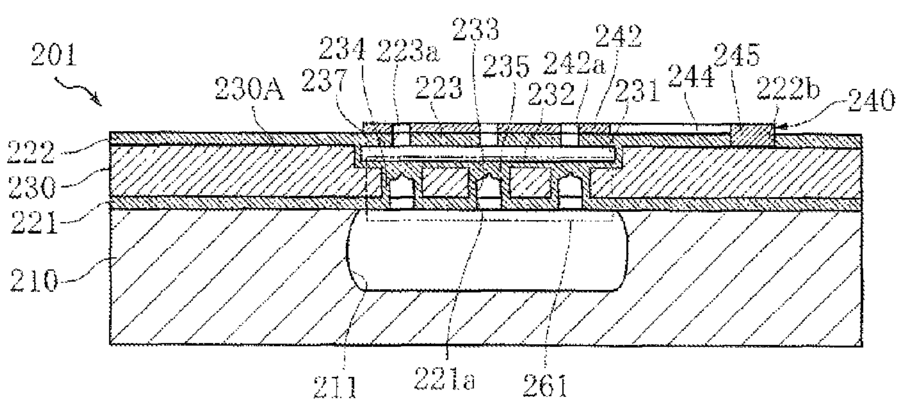

201
234 223a 233 235 242a 242
237 223 232 231 244 245
230A
222b
240
222
230
221
210
211
221a
261

FIG.88

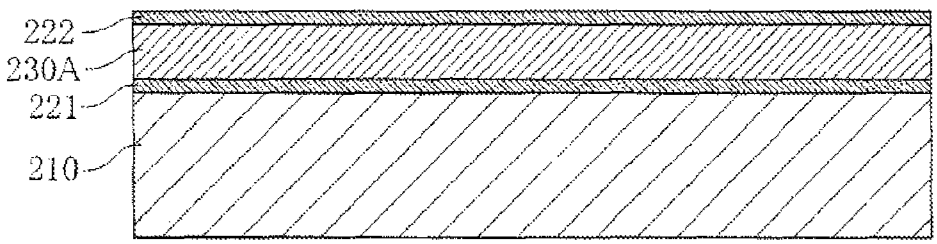


FIG.89

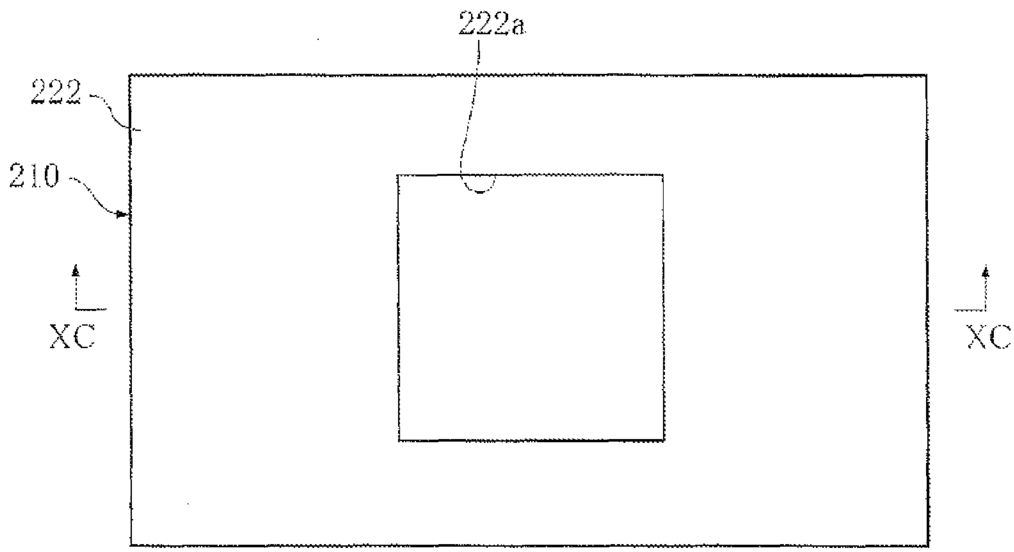


FIG.90

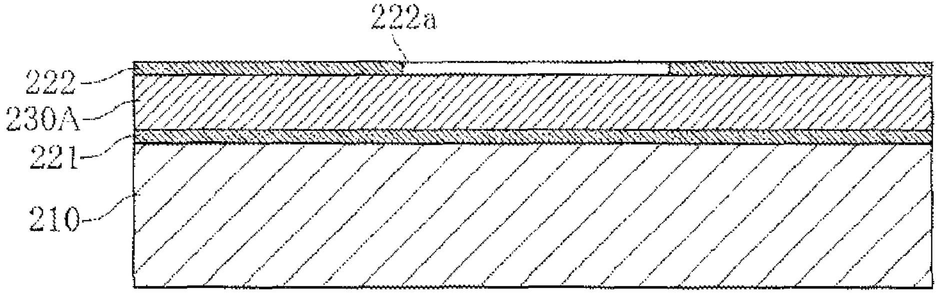


FIG.91

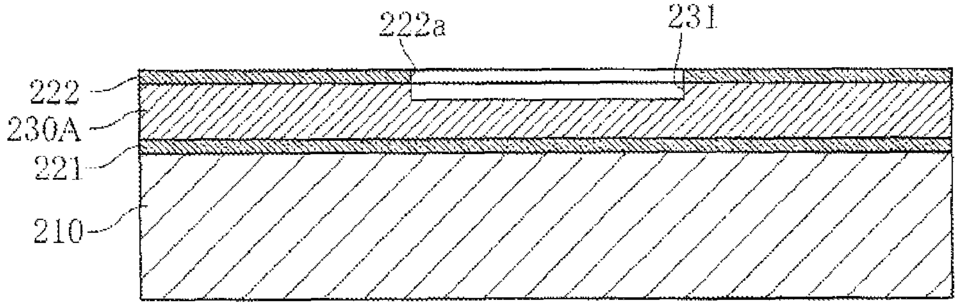


FIG.92

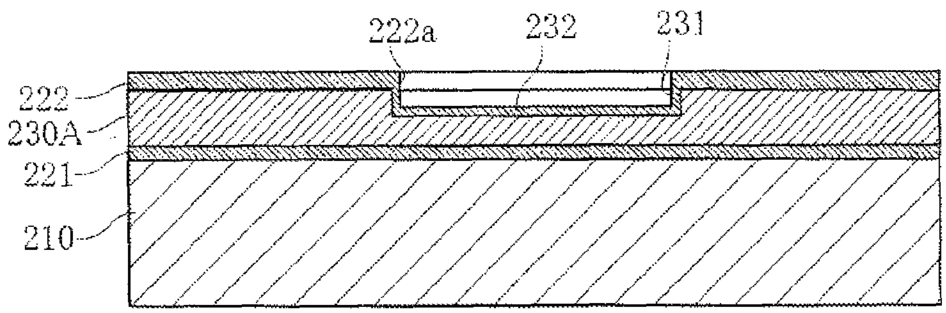


FIG.93

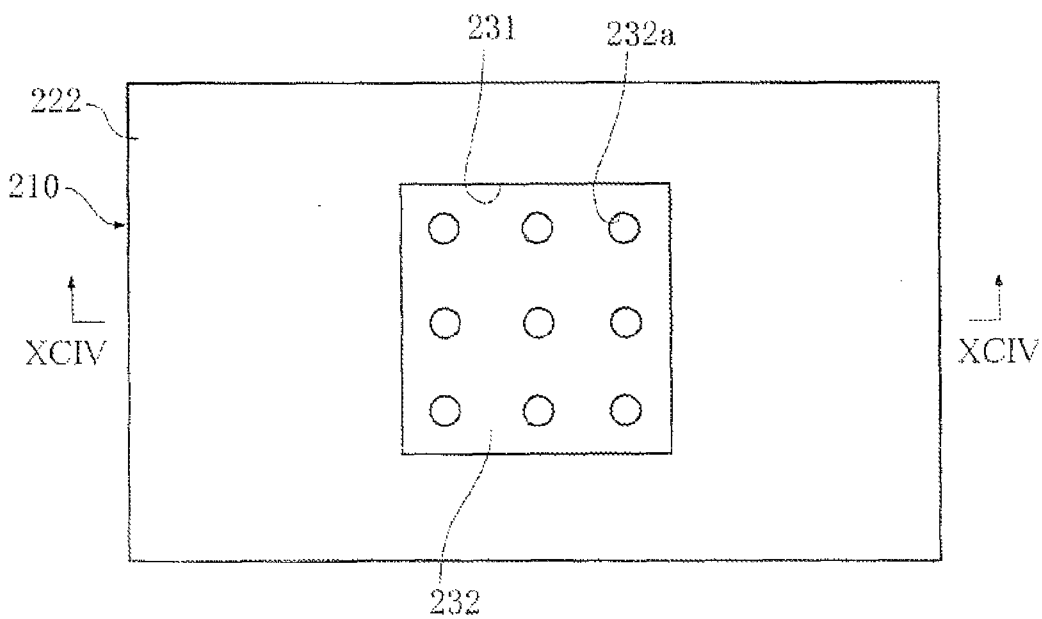


FIG.94

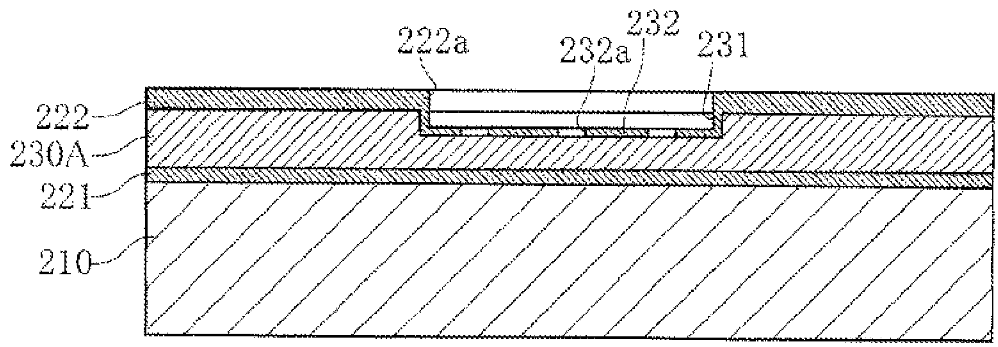


FIG.95

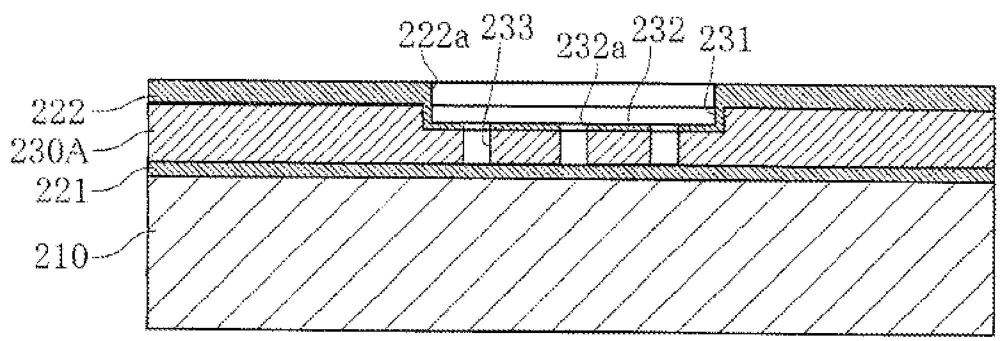


FIG.96

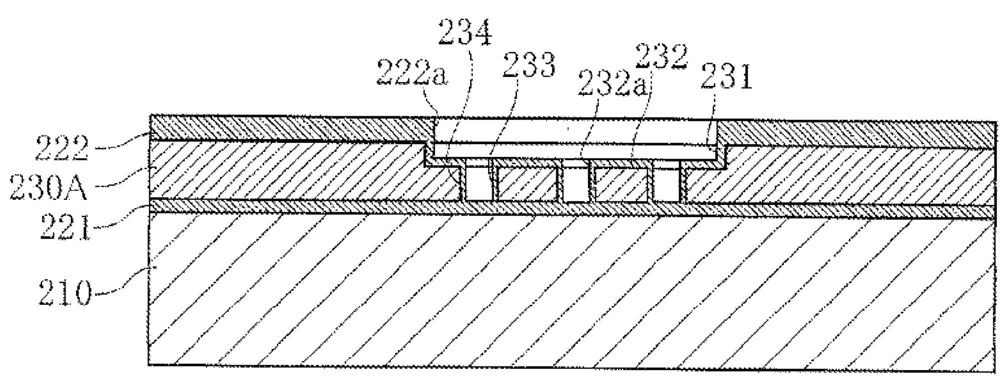


FIG.97

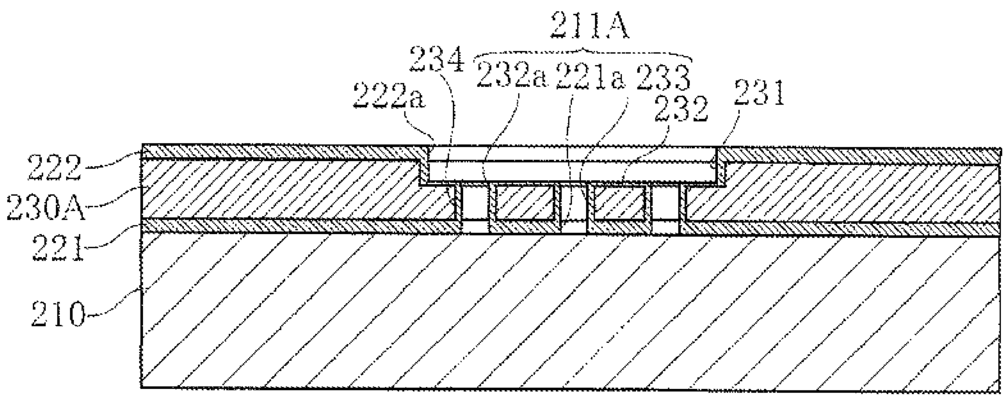

211A
234
232a
221a
233
222a
232
231
222
230A
221
210

FIG.98

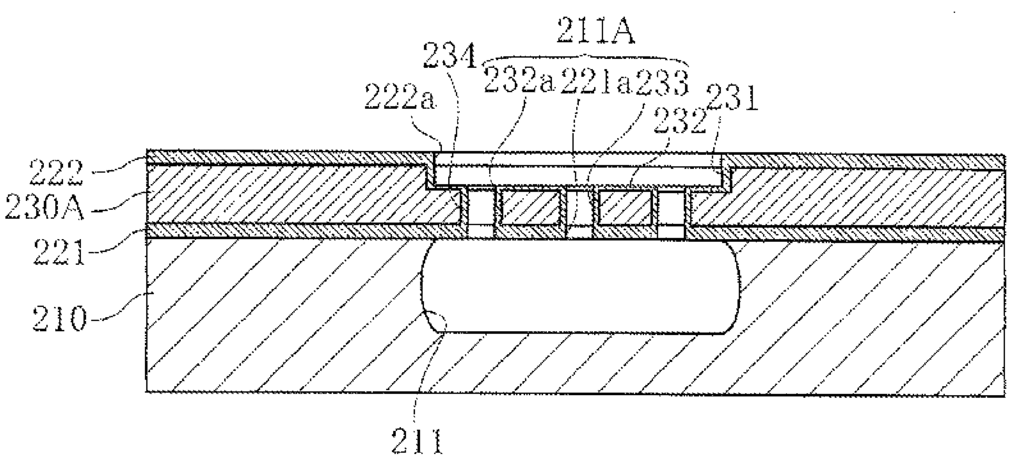

211A
234
232a
221a
233
222a
232
231
222
230A
221
210
211

FIG.99

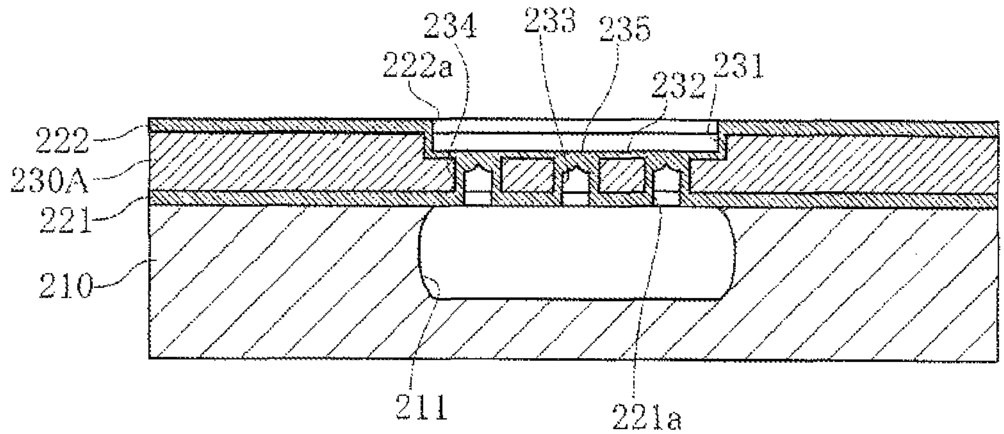


FIG.100

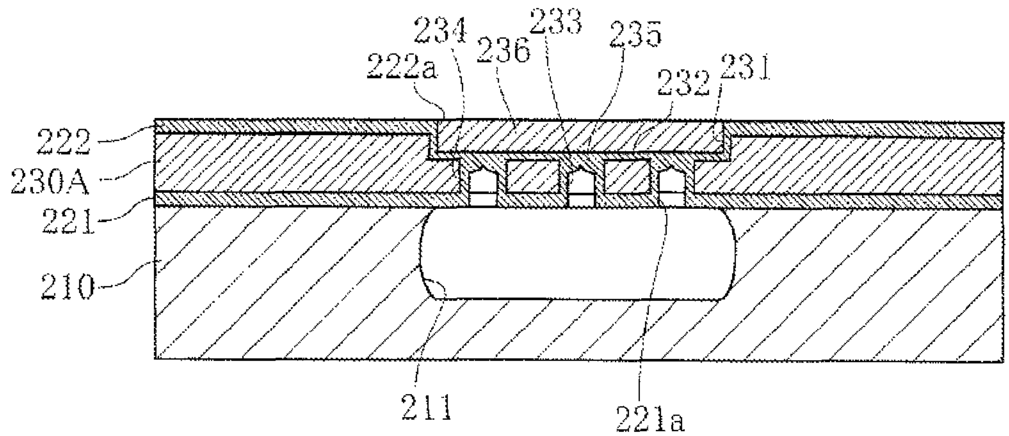


FIG.101

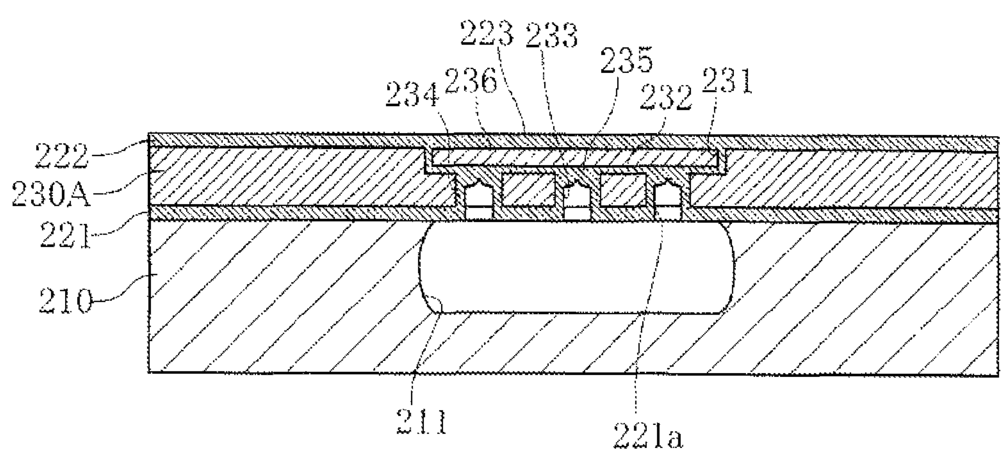


FIG.102

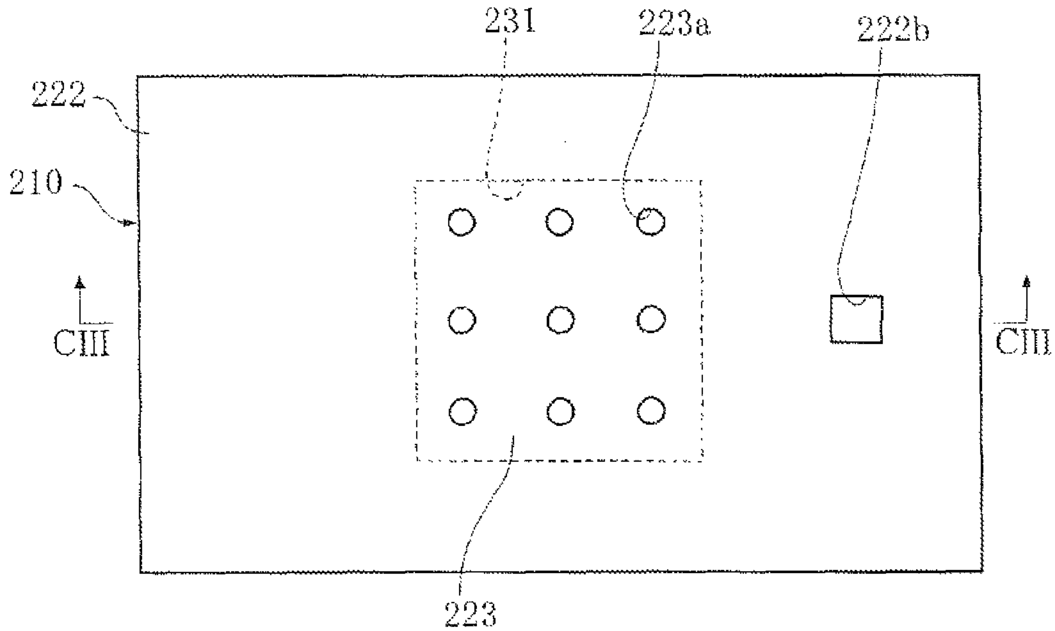


FIG. 103

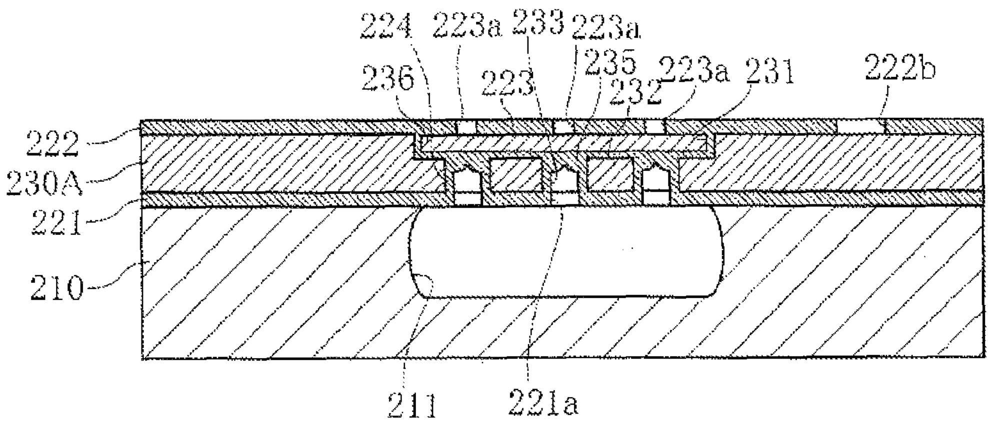


FIG. 104

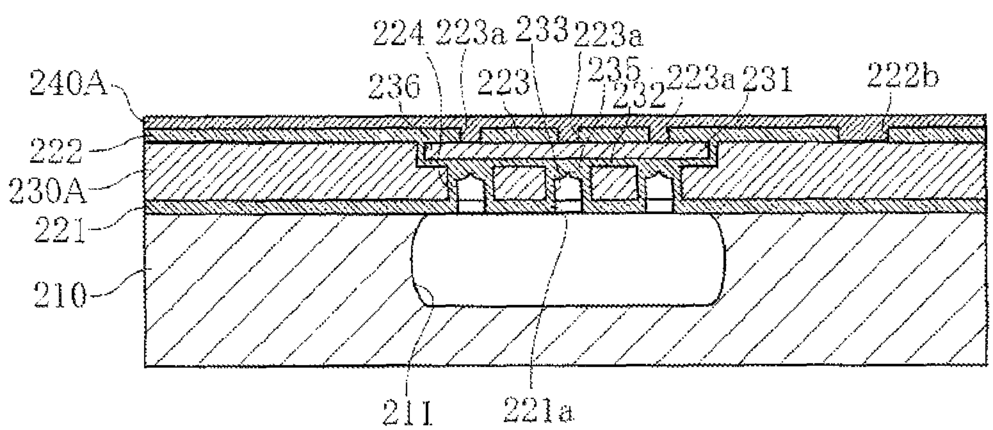


FIG.105

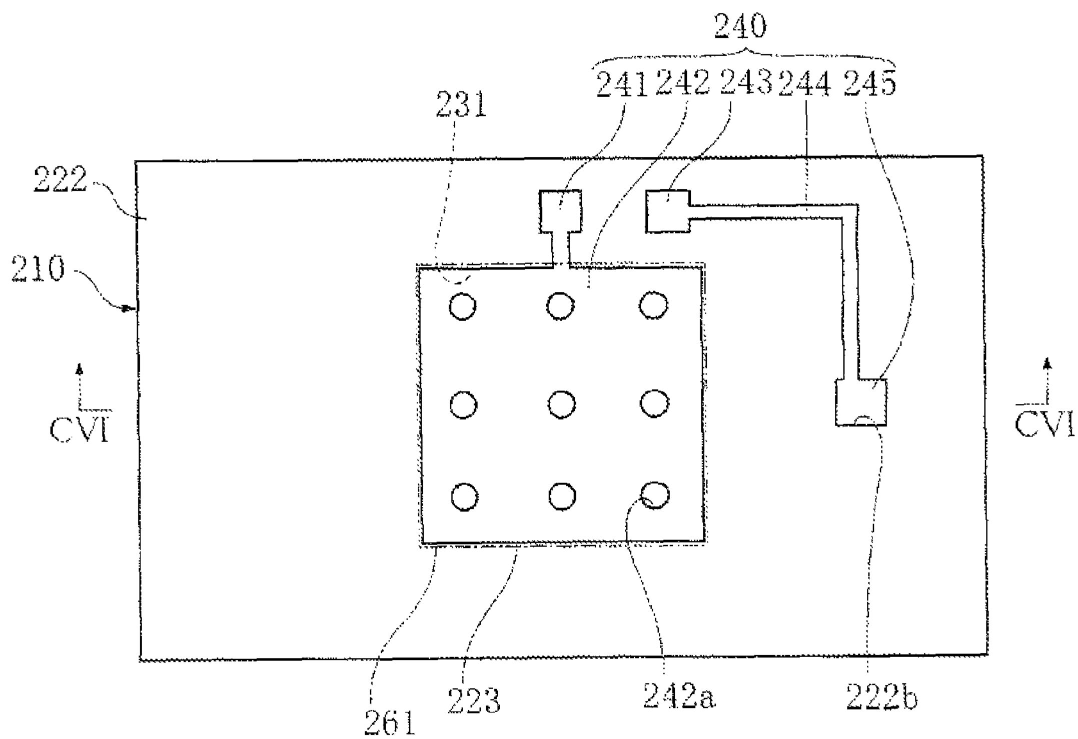


FIG.106

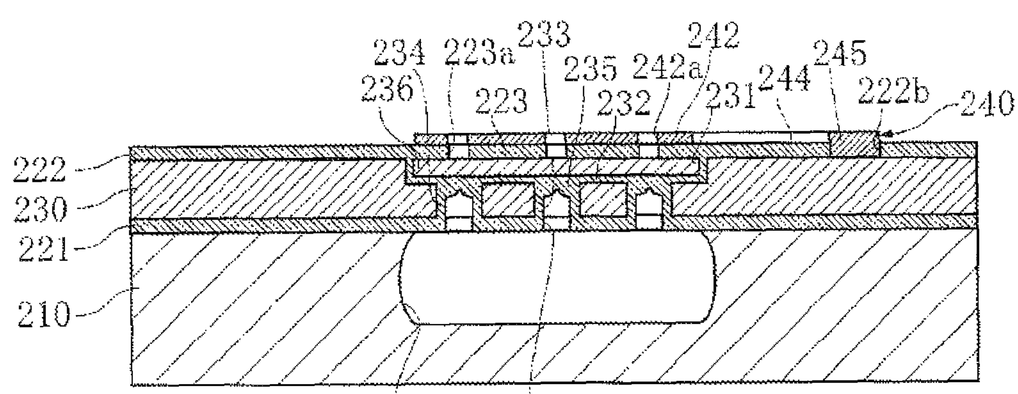


FIG.107

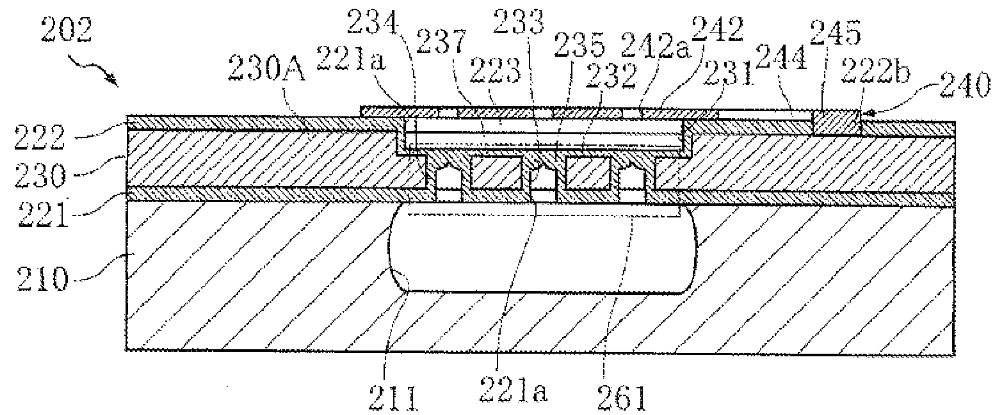


FIG.108

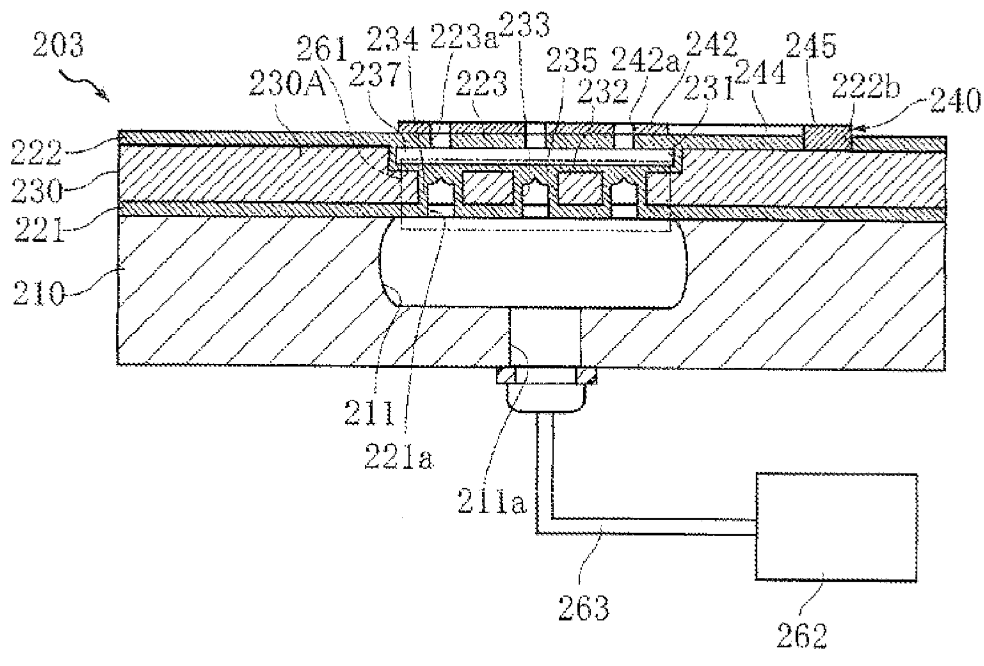


FIG.109

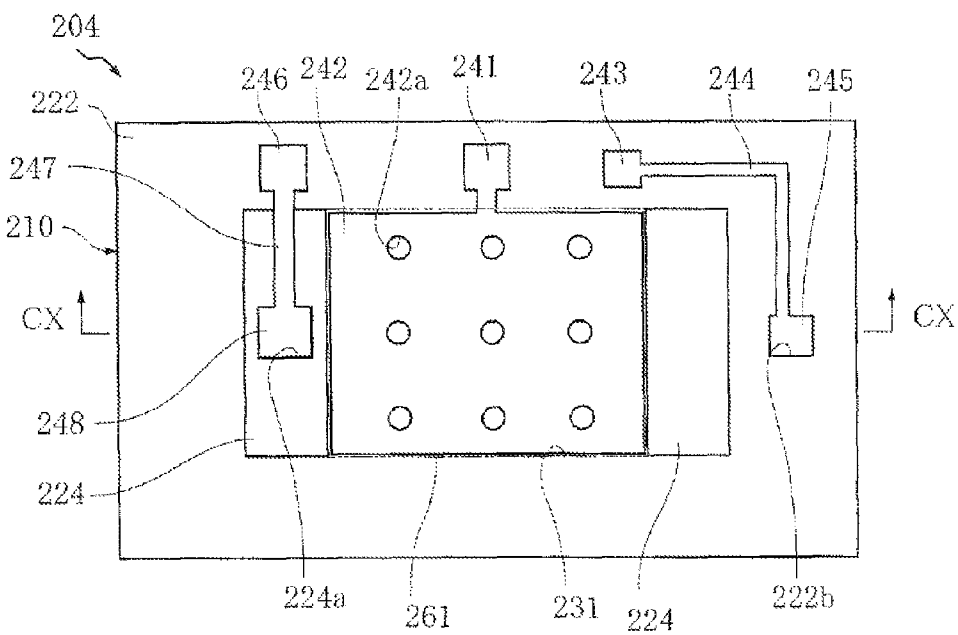


FIG.110

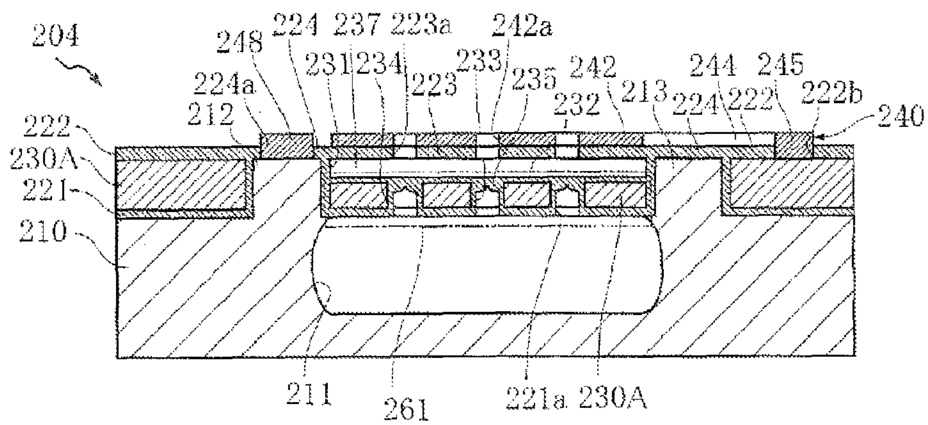


FIG.111

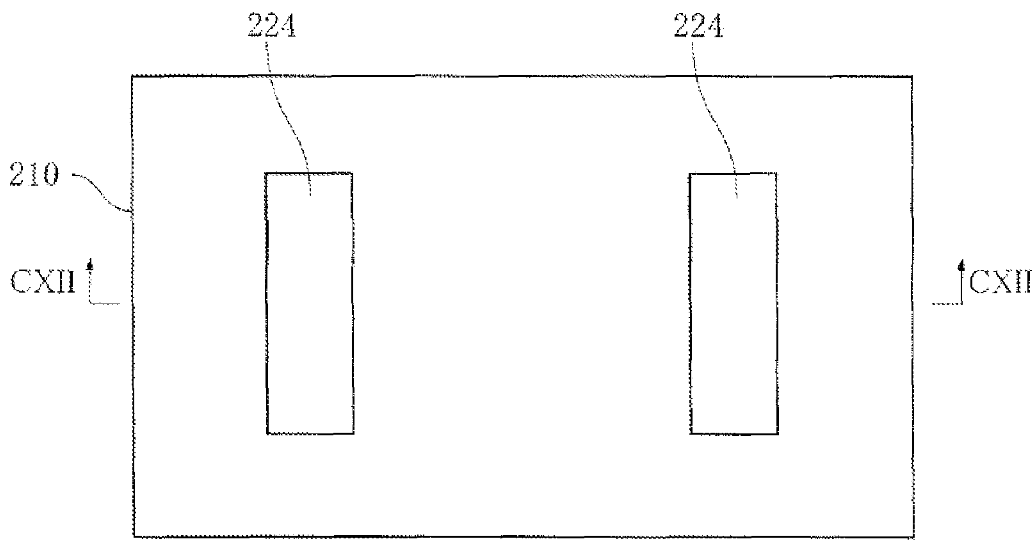


FIG.112

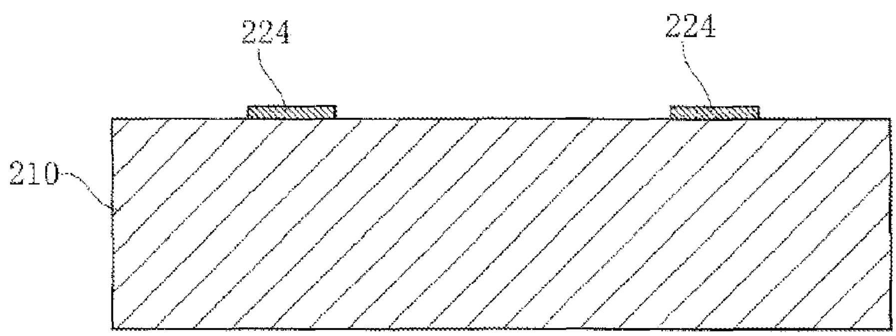


FIG.113

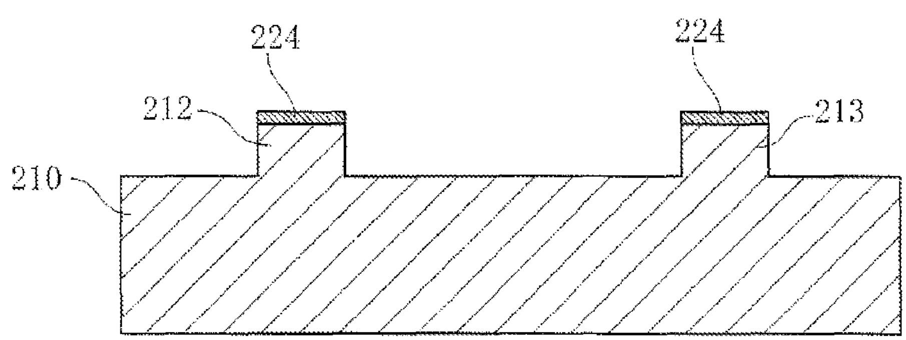


FIG.114

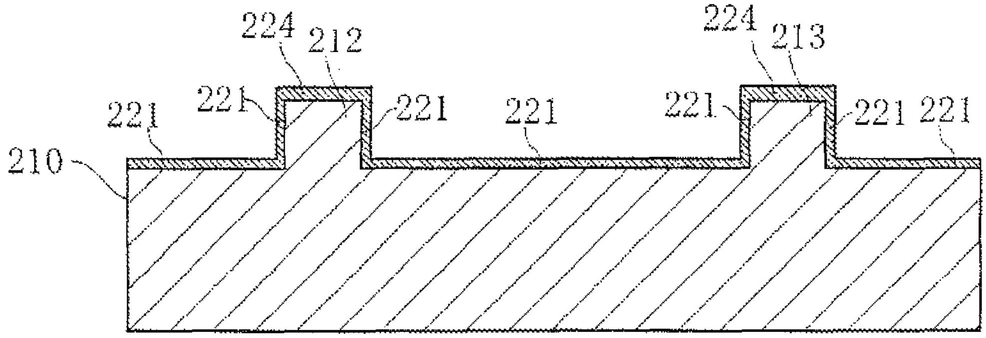


FIG.115

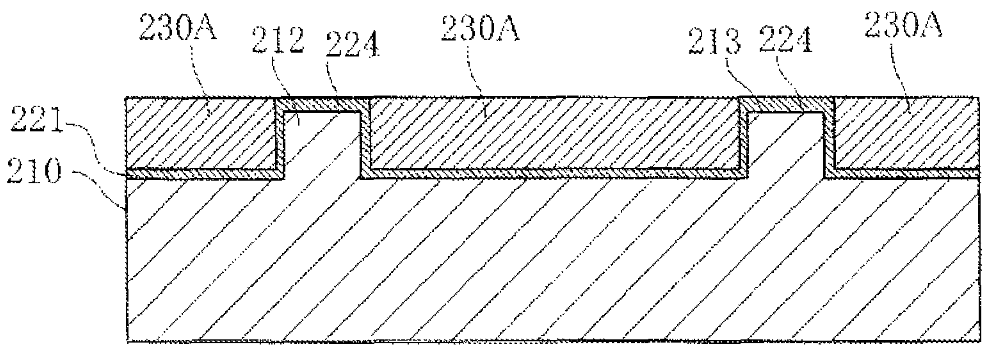


FIG.116

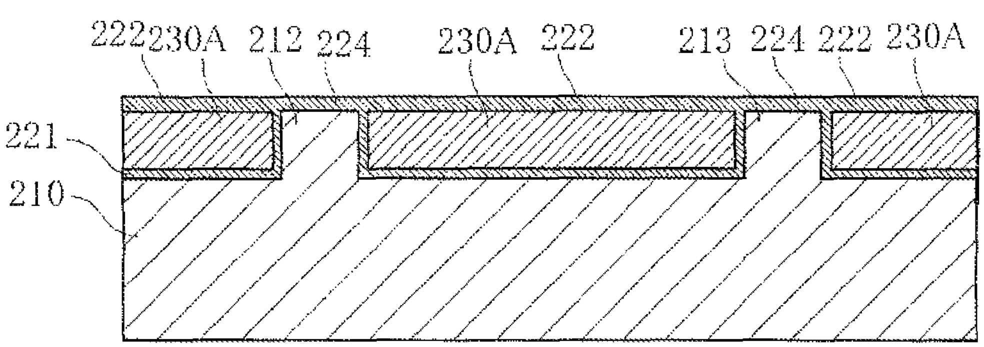


FIG.117

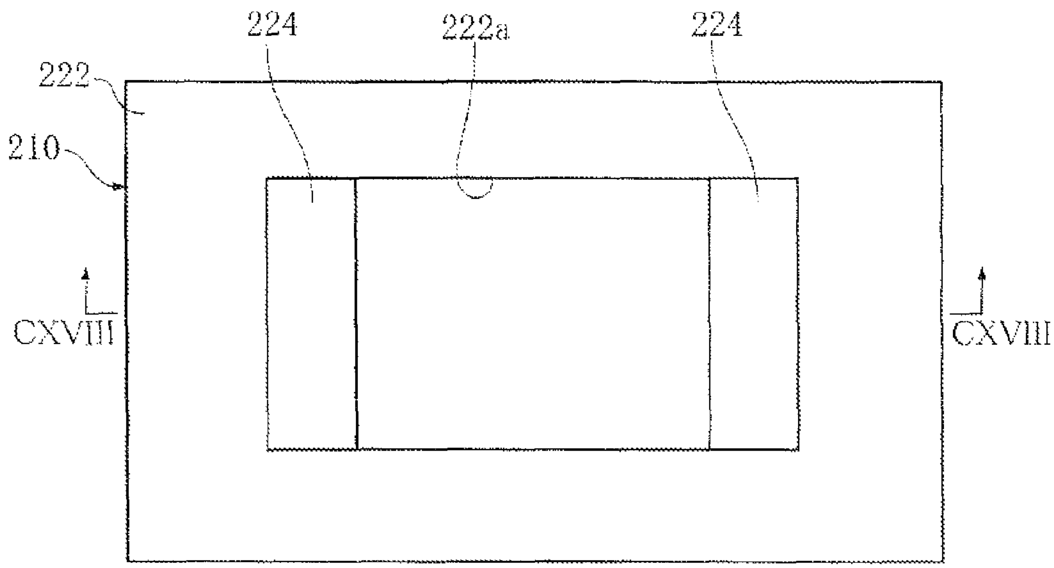


FIG.118

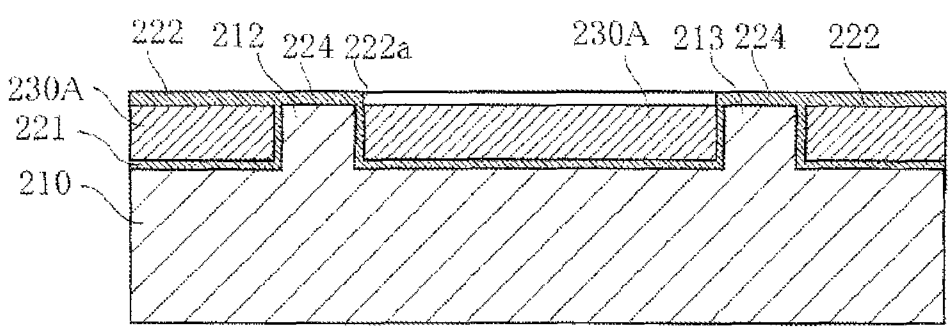


FIG.119

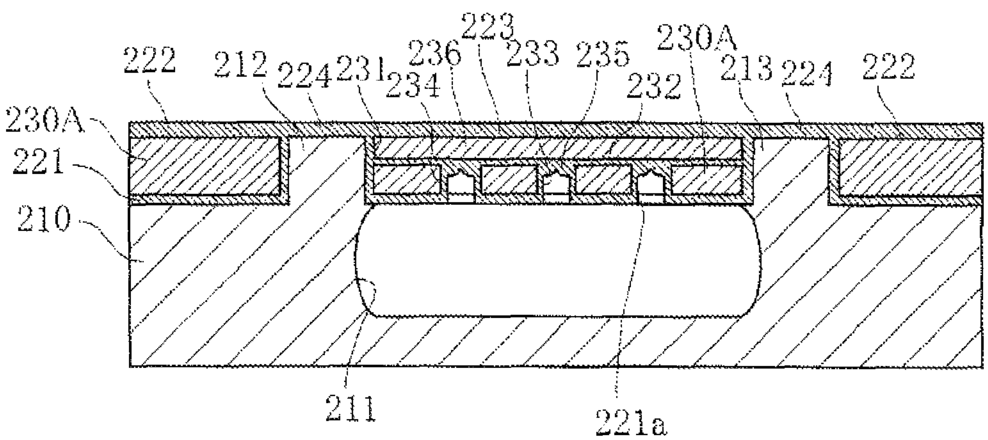

222
212
224
231
234
236
223
233
235
232
230A
213
224
222
230A
221
210
211
221a

FIG.120

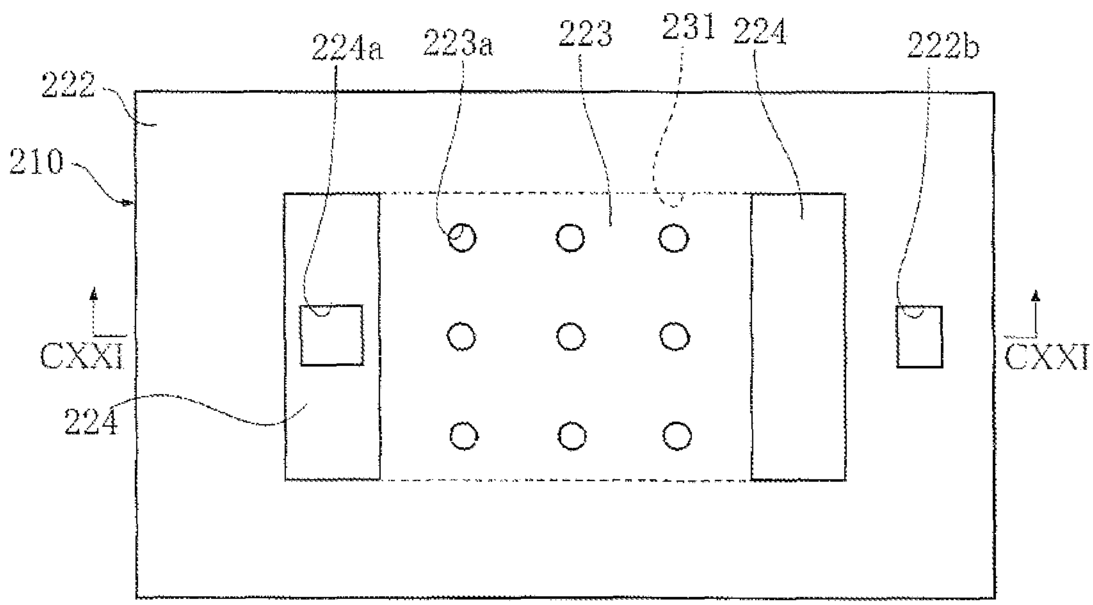


FIG.121

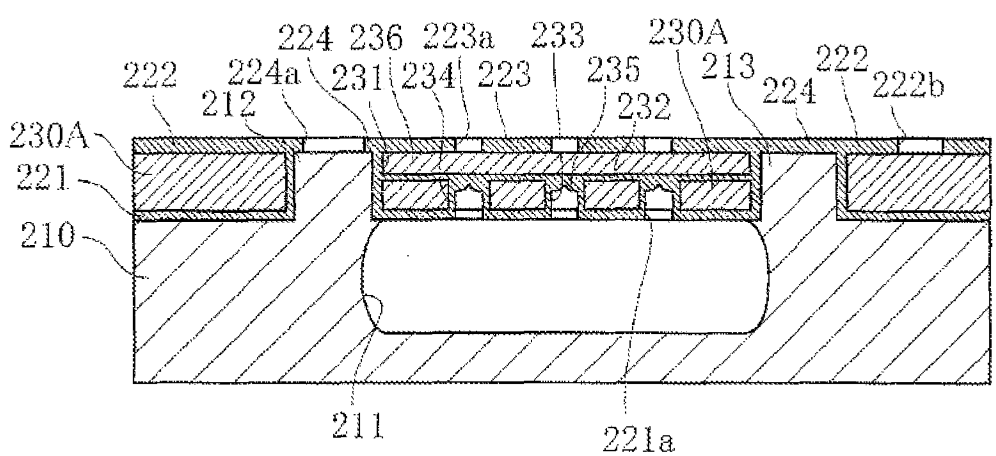


FIG.122

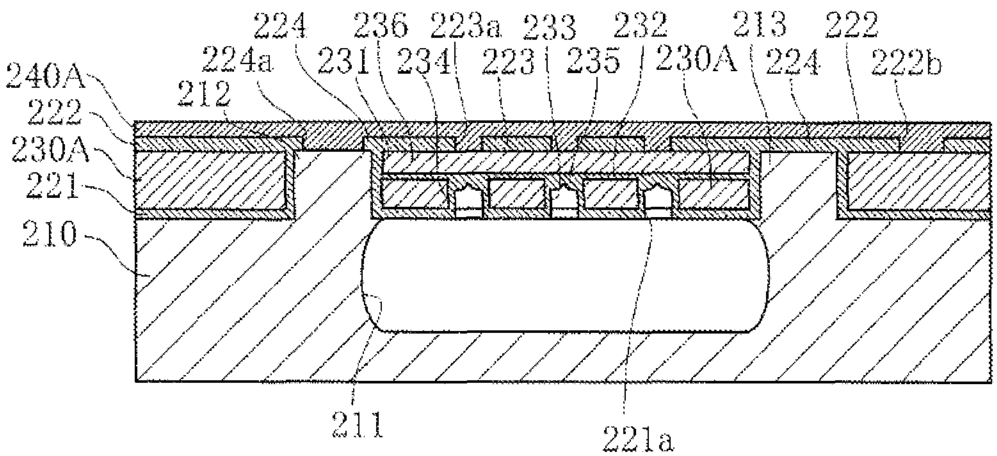

224
236
223a
233
232
213
222
224a
231
234
223
235
230A
224
222b
240A
212
222
230A
221
210
211
221a

FIG.123

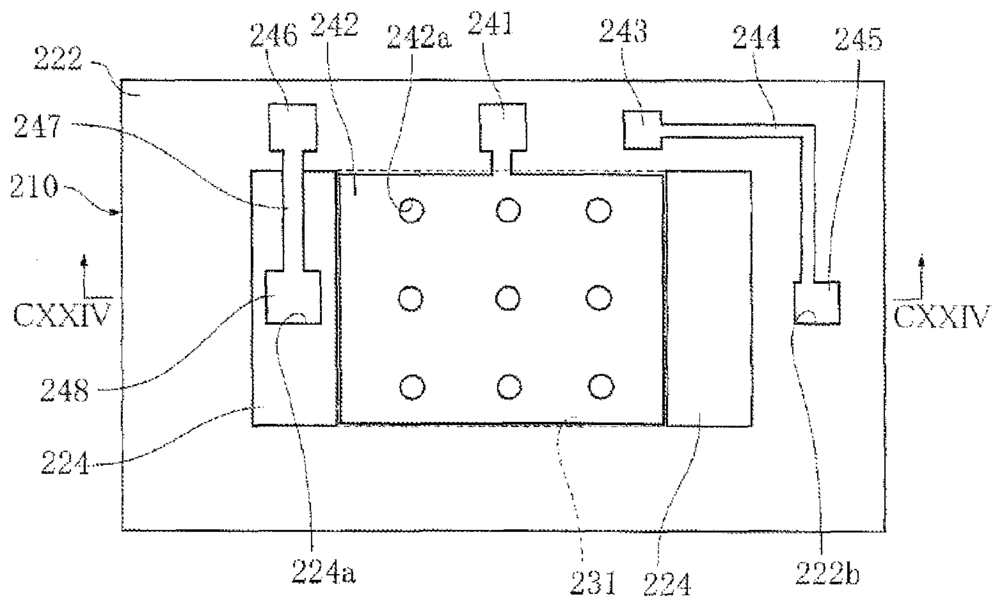


FIG.124

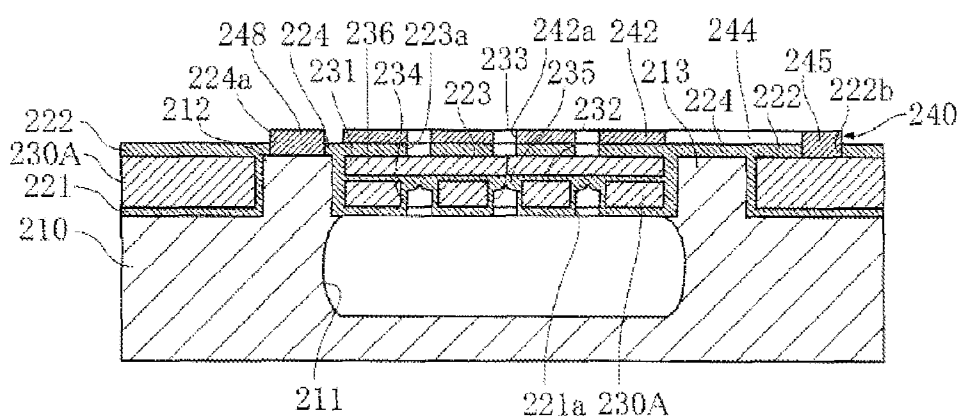


FIG.125

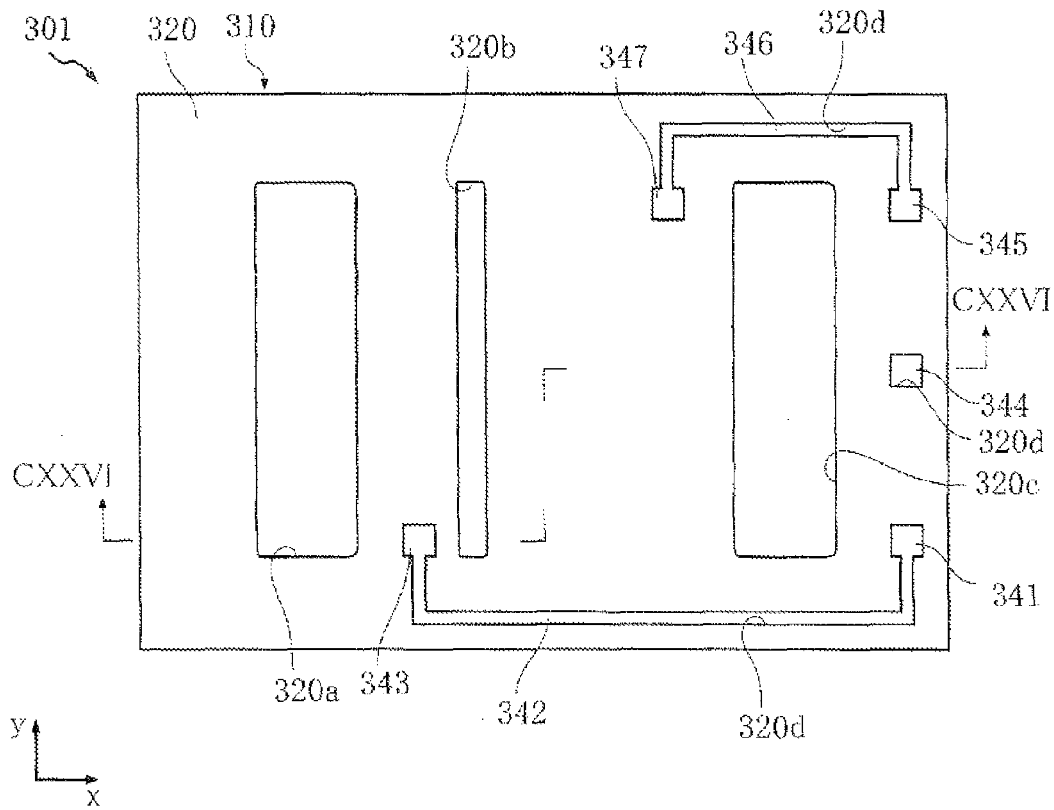

301
320
310
320b
347
346
320d
345
CXXVI
344
320d
320c
CXXVI
341
320a
343
342
320d
y
x

FIG.126

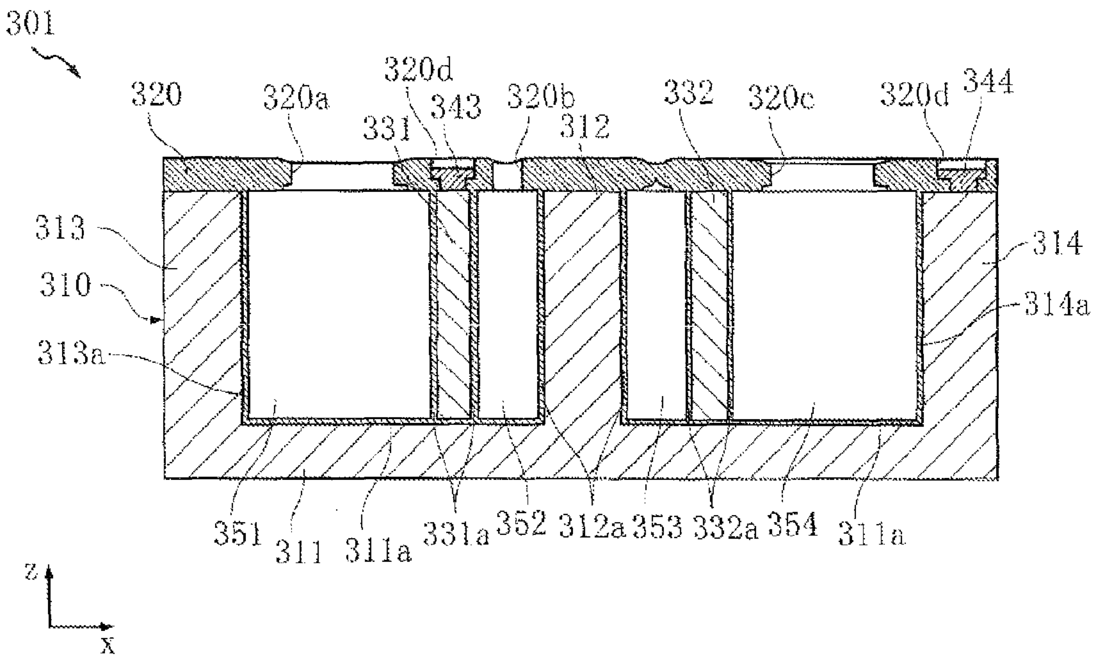

301
320
320a
320d
331
343
320b
312
332
320c
320d
344
313
310
313a
314
314a
351
311
311a
331a
352
312a
353
332a
354
311a
z
x

FIG.127

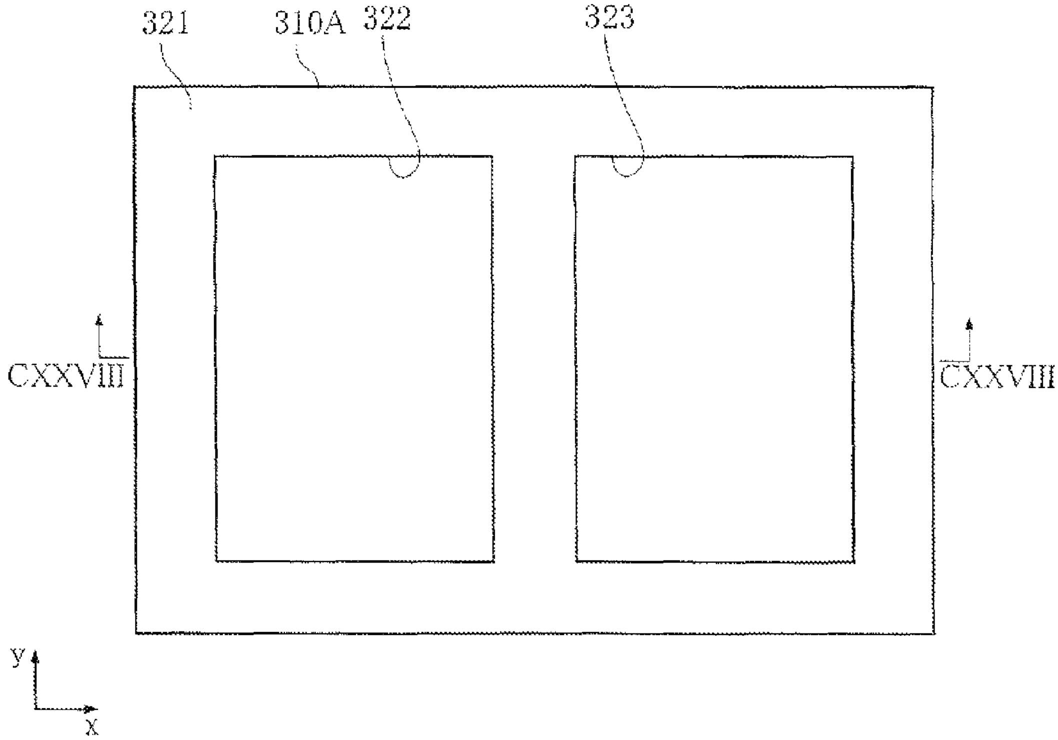


FIG.128

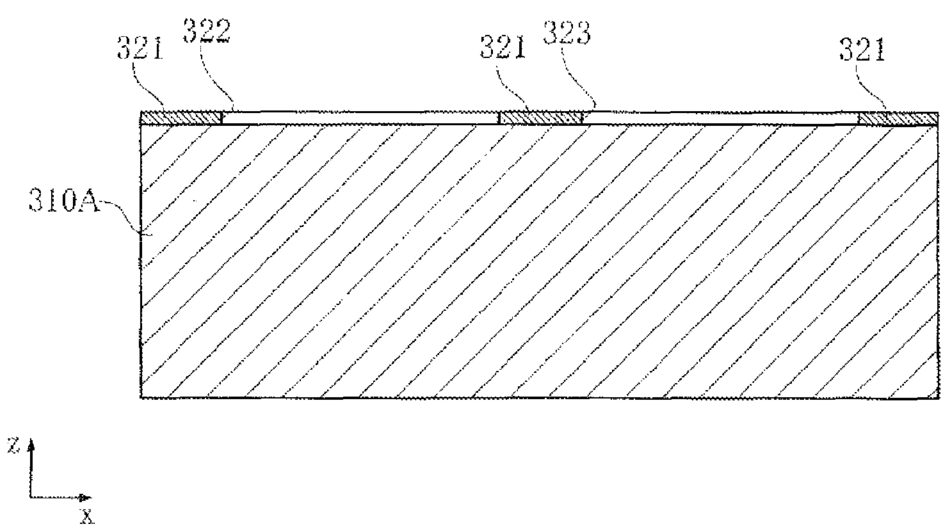


FIG.129

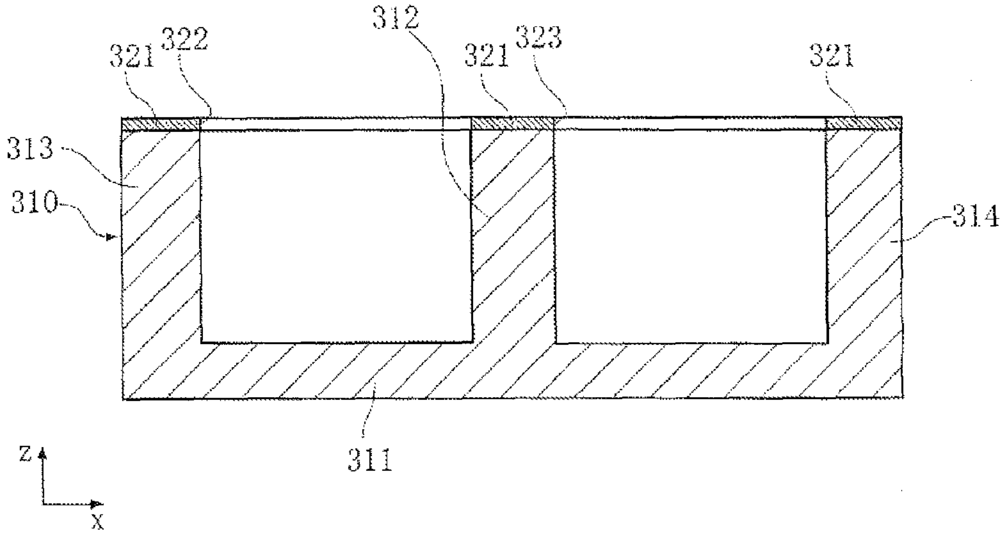


FIG.130

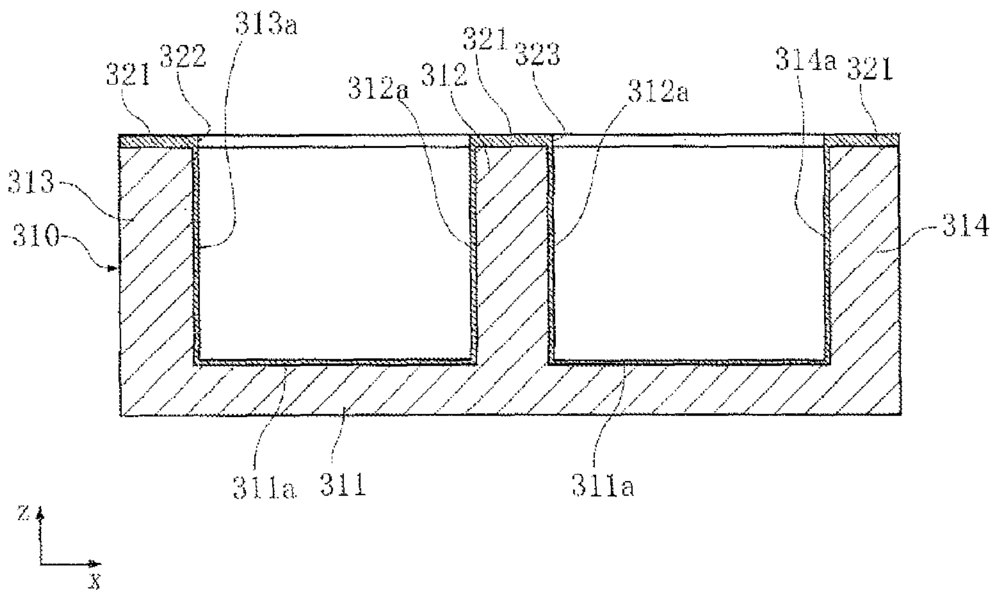


FIG.131

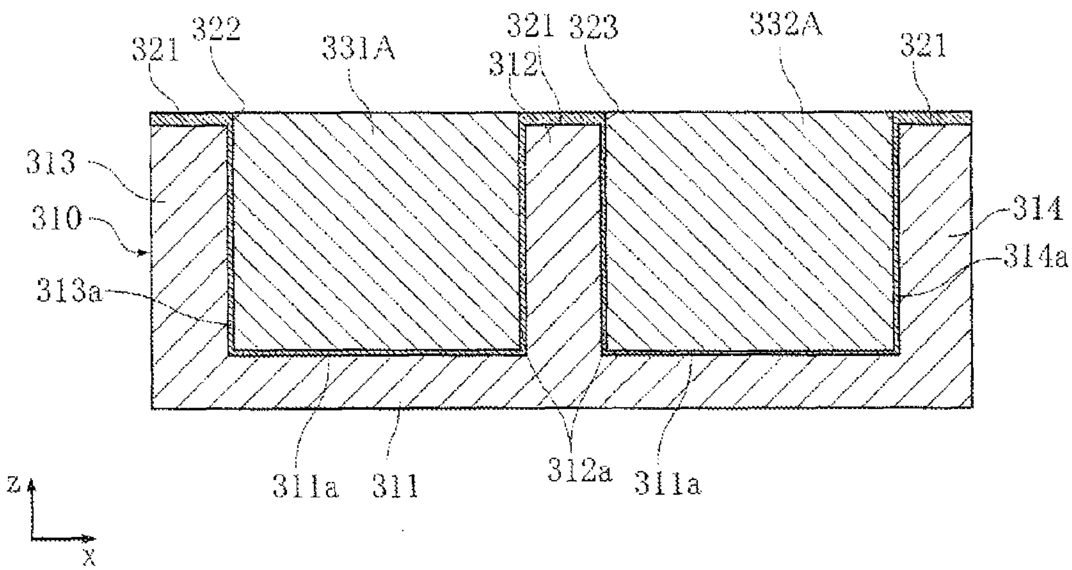


FIG.132

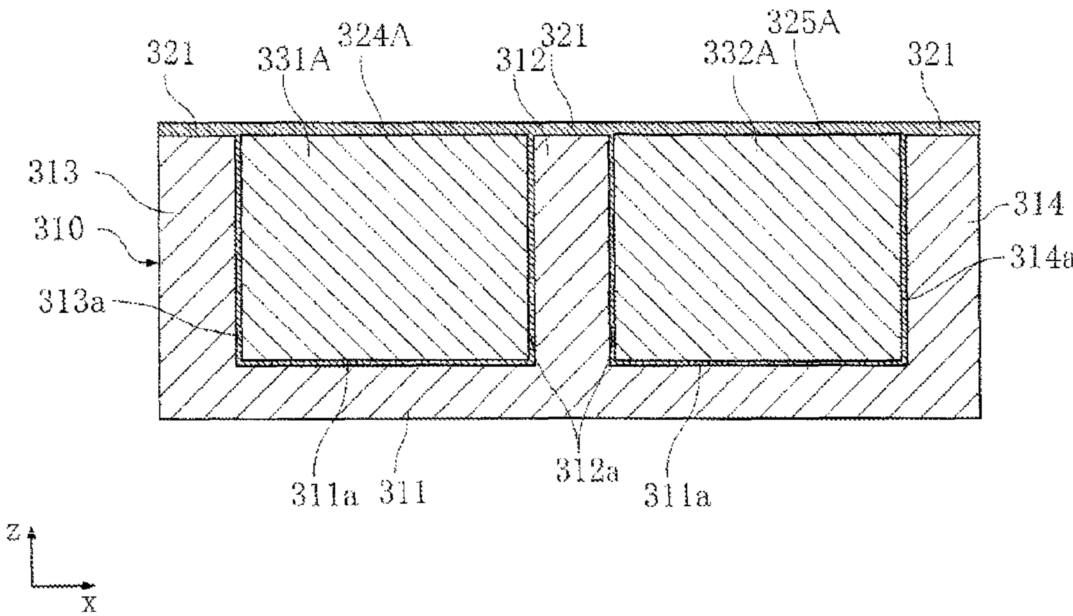


FIG.133

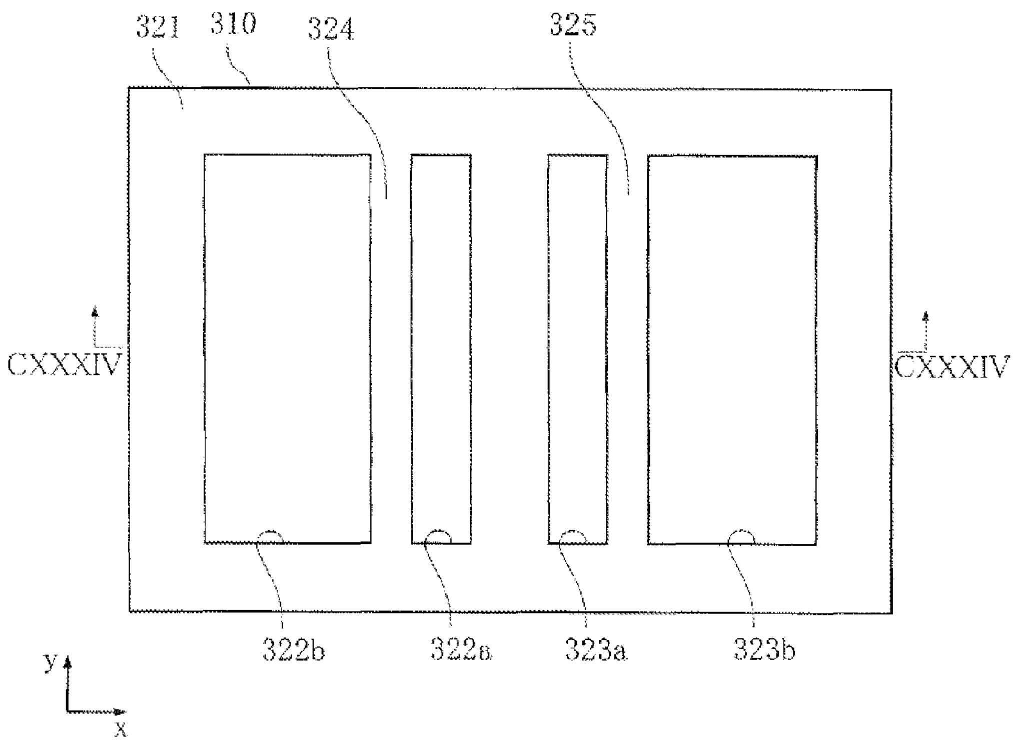


FIG.134

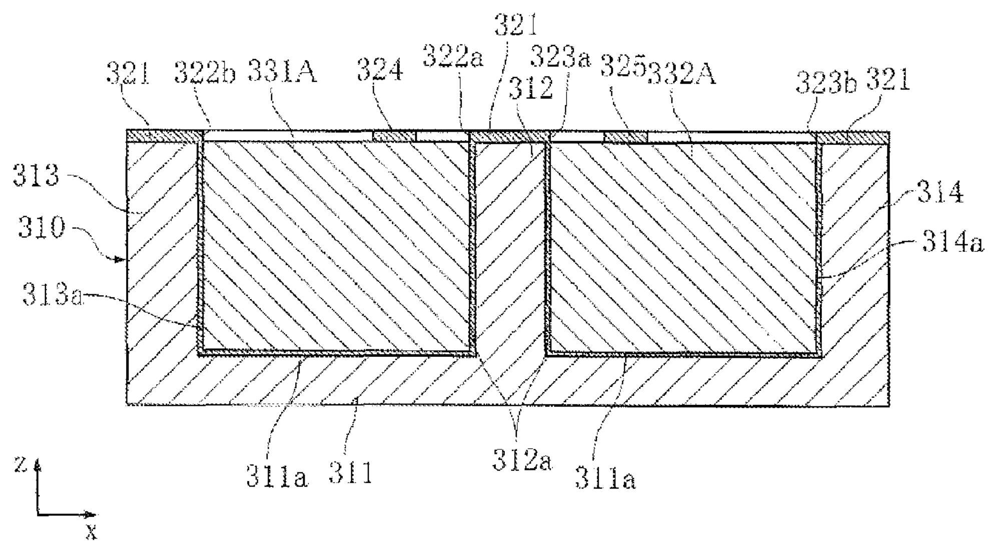


FIG.135

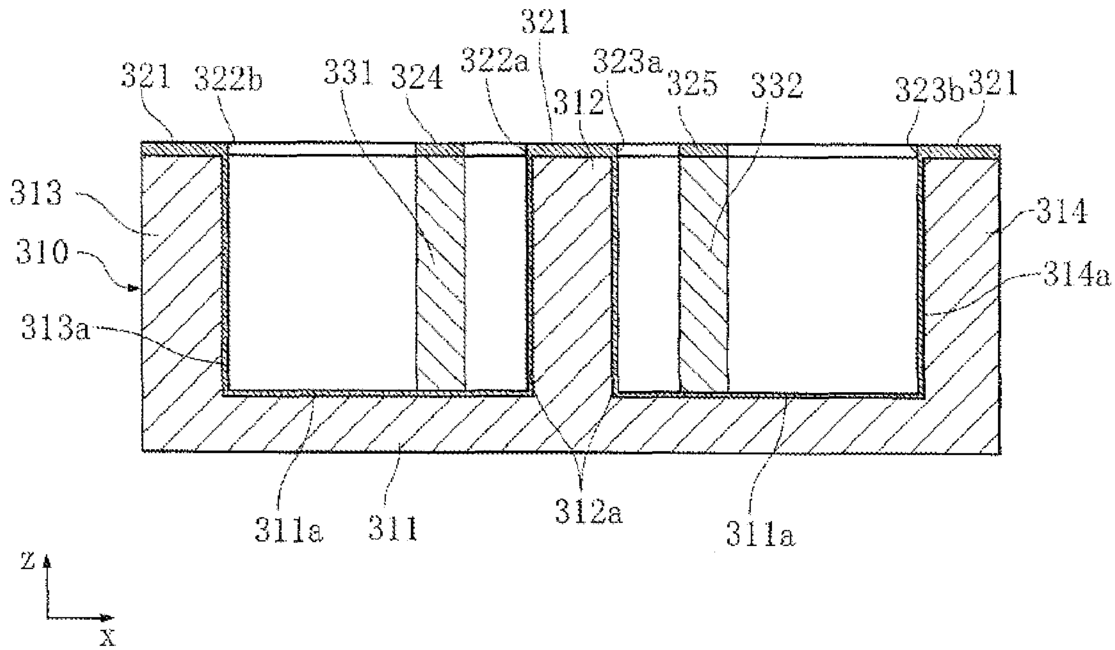


FIG.136

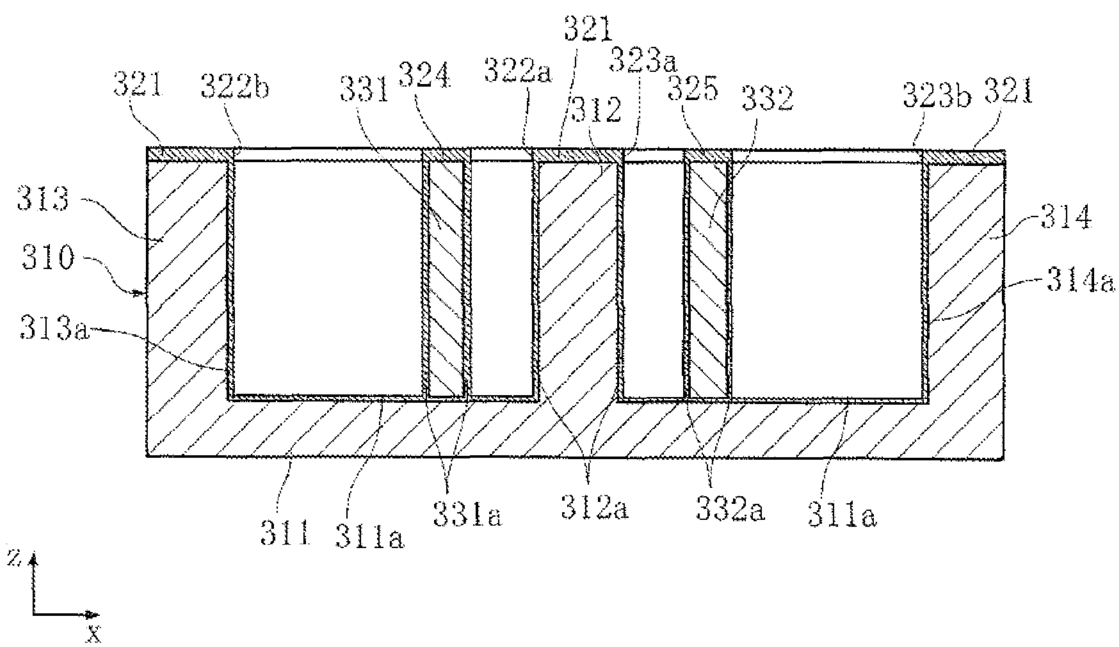


FIG.137

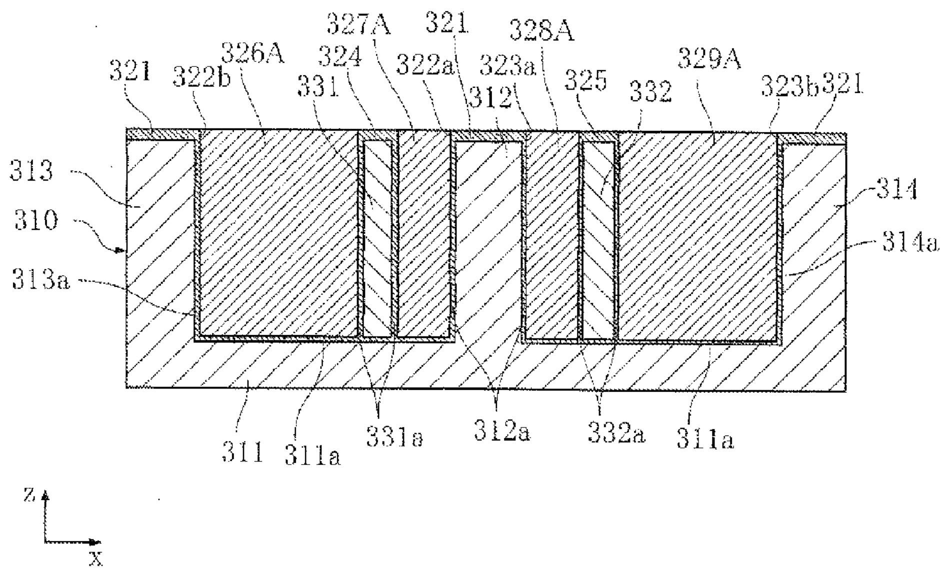


FIG.138

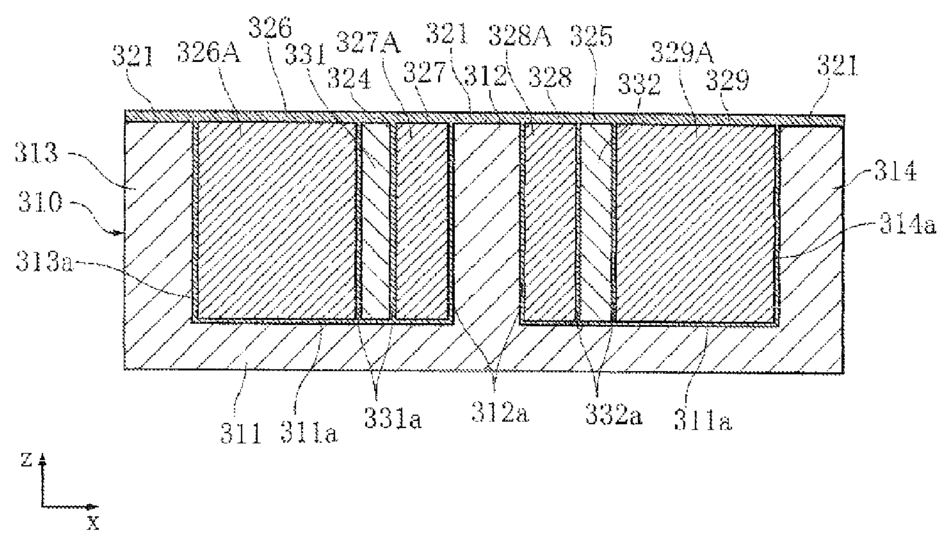


FIG.139

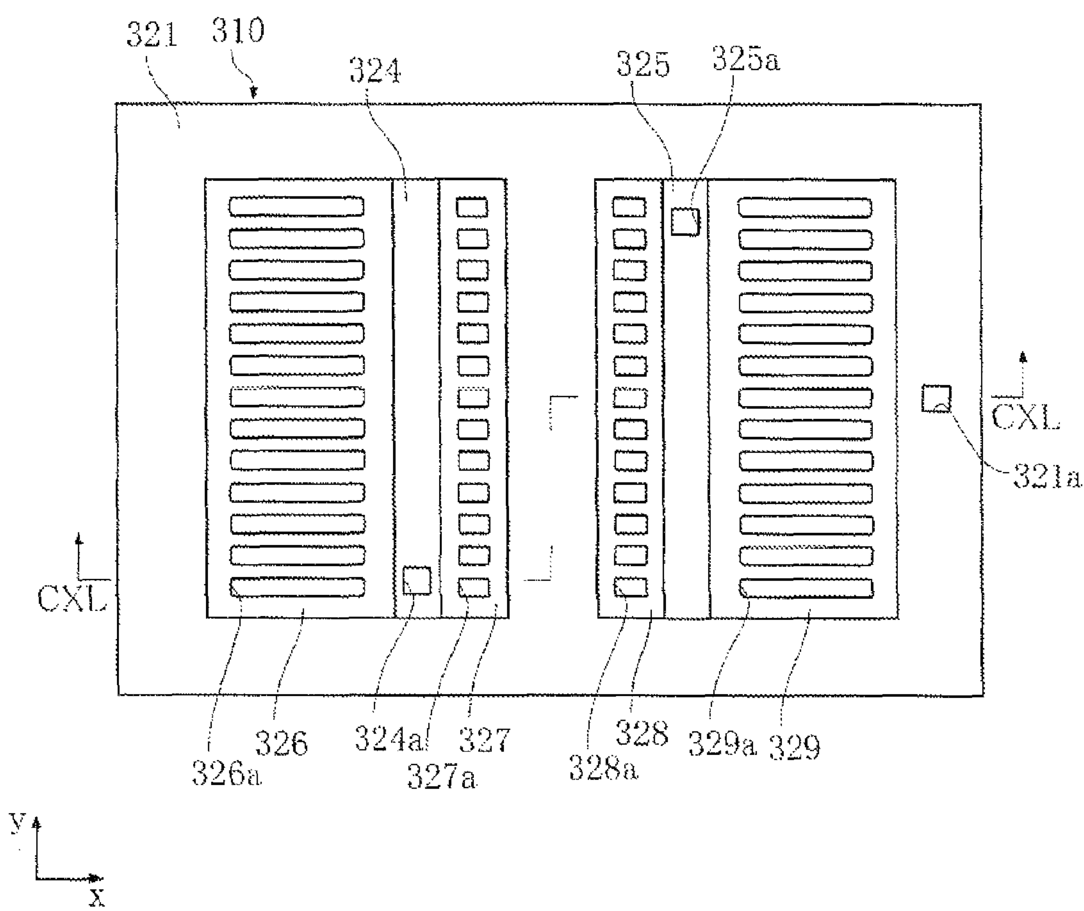

321
310
324
325
325a
CXL
321a
CXL
326a
326
324a
327
327a
328a
328
329a
329
y
x

FIG.140

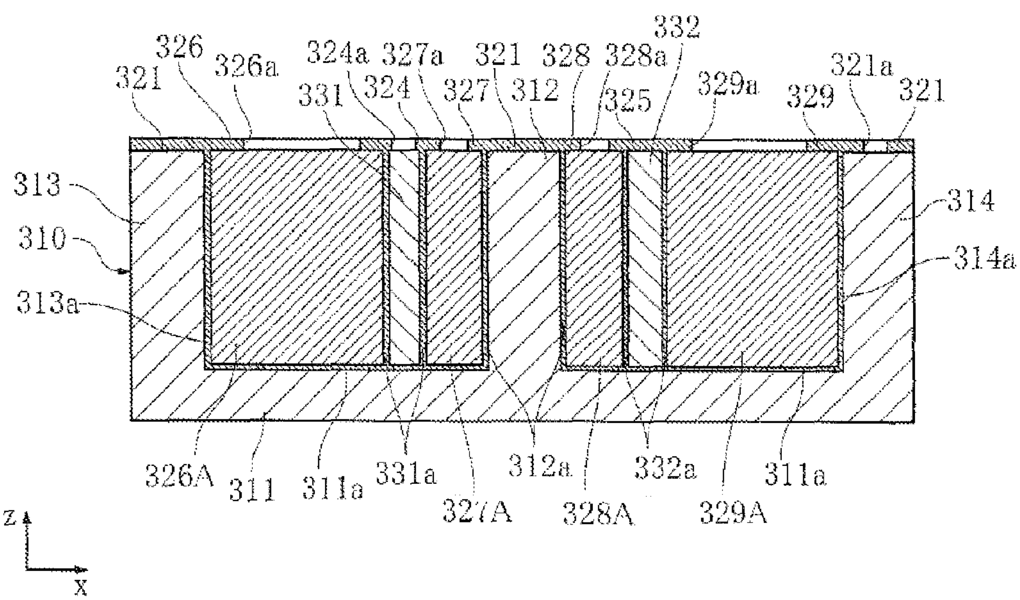

326
321
326a
324a
327a
331
324
327
321
312
328
328a
332
325
329a
329
321a
321
313
310
313a
314
314a
326A
311
311a
331a
327A
312a
328A
332a
329A
311a
z
x

FIG.141

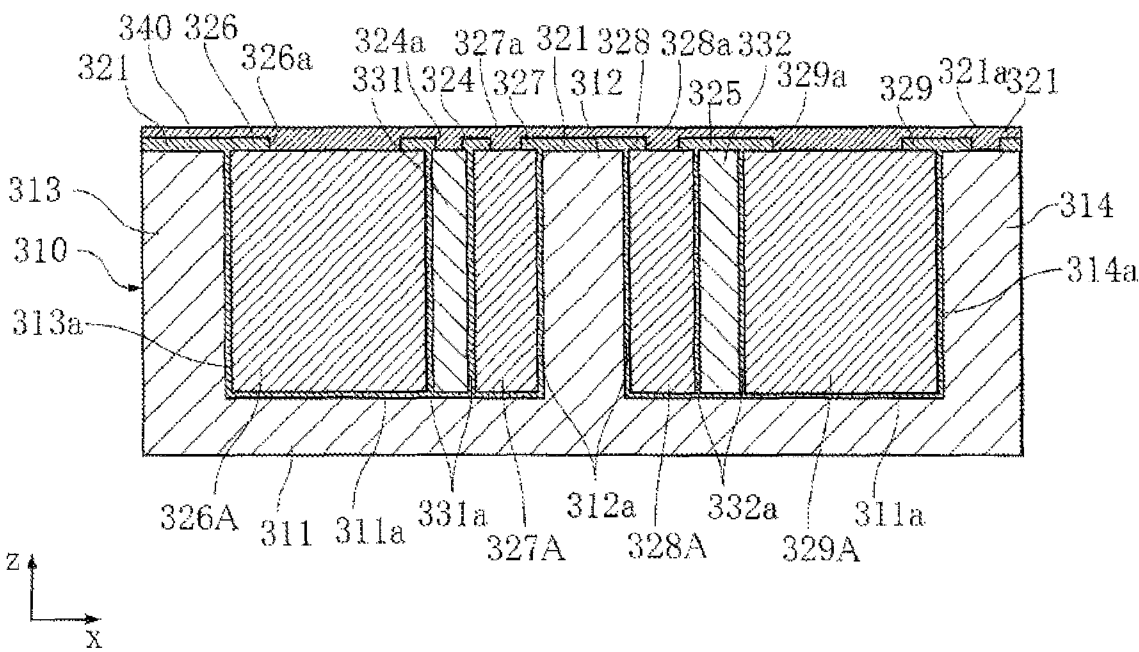

340 326
326a
321
324a
331 324
327a
327
321 328
312
328a 332
325
329a
329
321a 321
313
310
313a
314
314a
326A
311
311a
331a
327A
312a
328A
332a
329A
311a
z
x

FIG.142

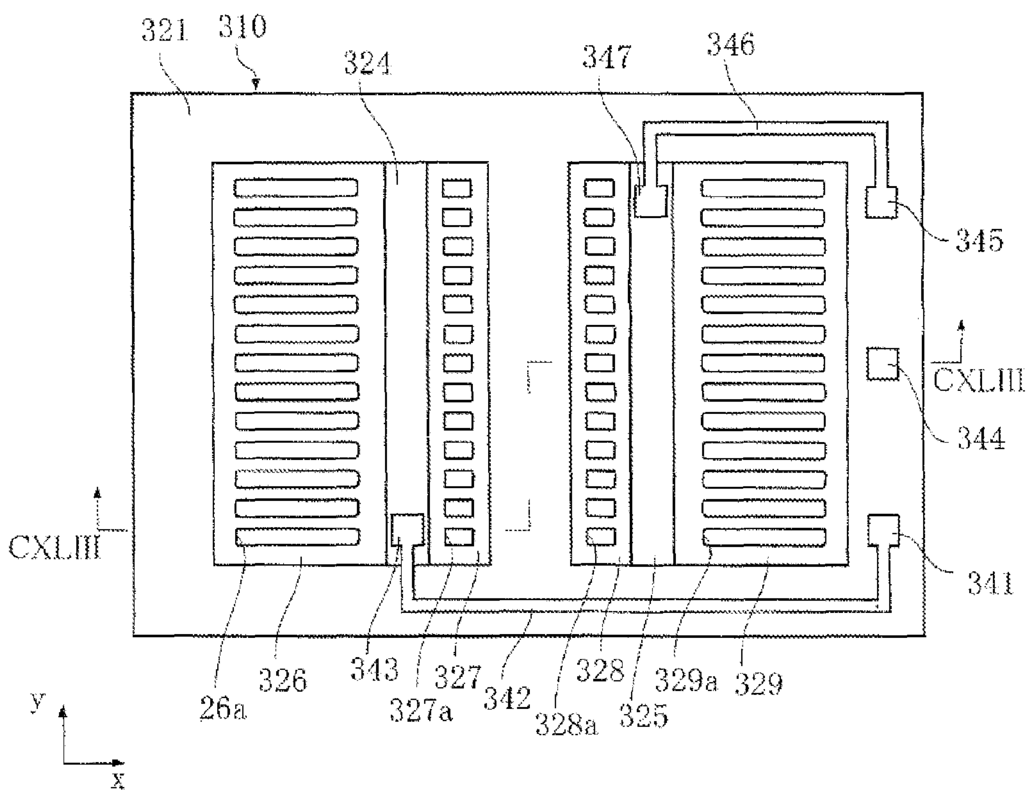

321
310
324
347
346
345
344
CXLIII
CXLIII
341
26a
326
343
327a
327
342
328a
328
325
329a
329
y
x

FIG.143

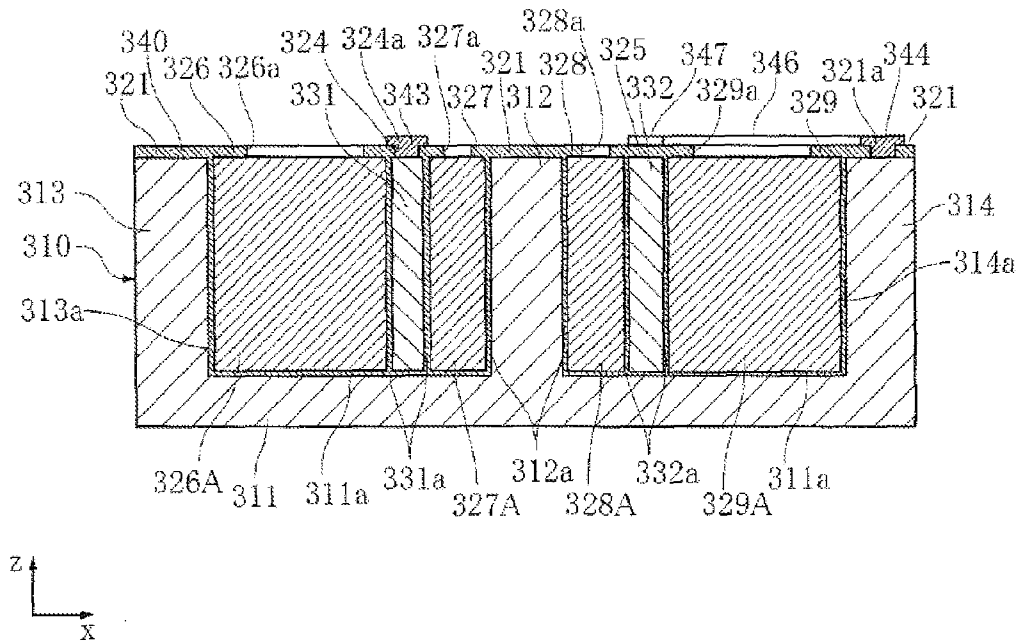


FIG.144

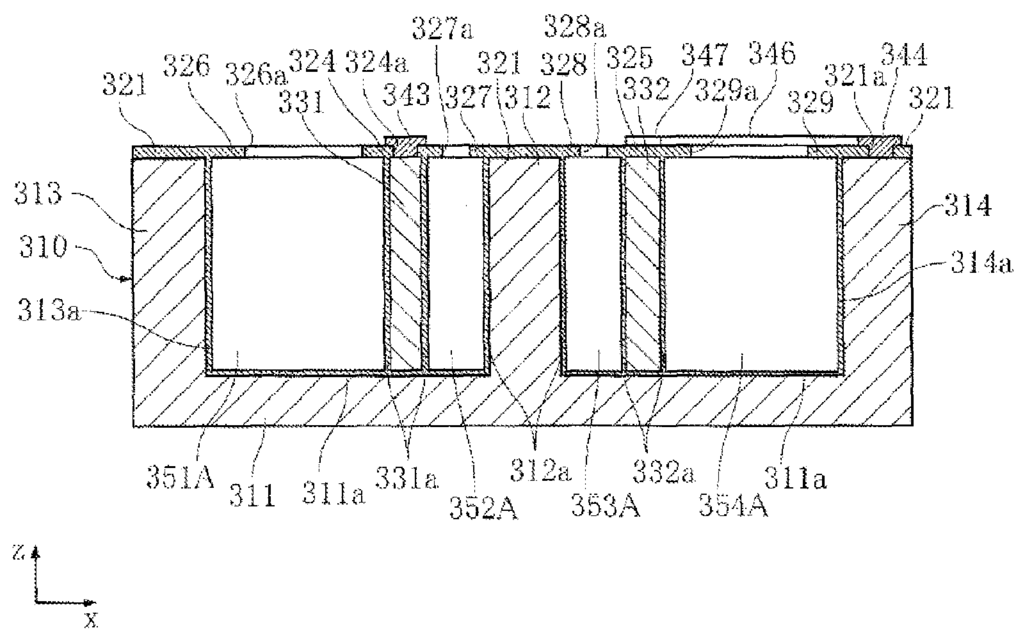


FIG.145

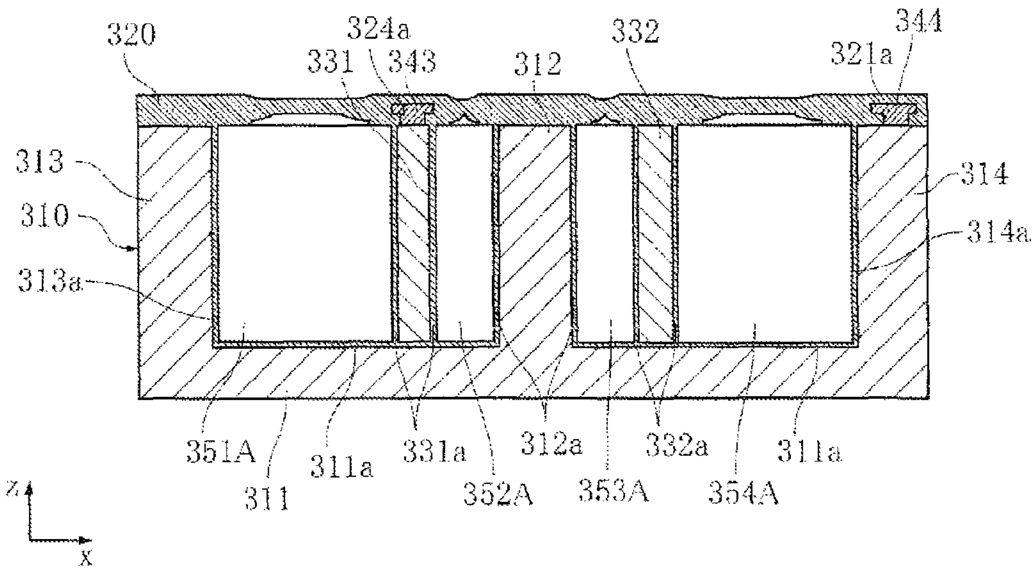

320
324a
331
343
312
332
321a
344
313
310
313a
314
314a
351A
311
311a
331a
352A
312a
353A
332a
354A
311a
z
x

FIG.146

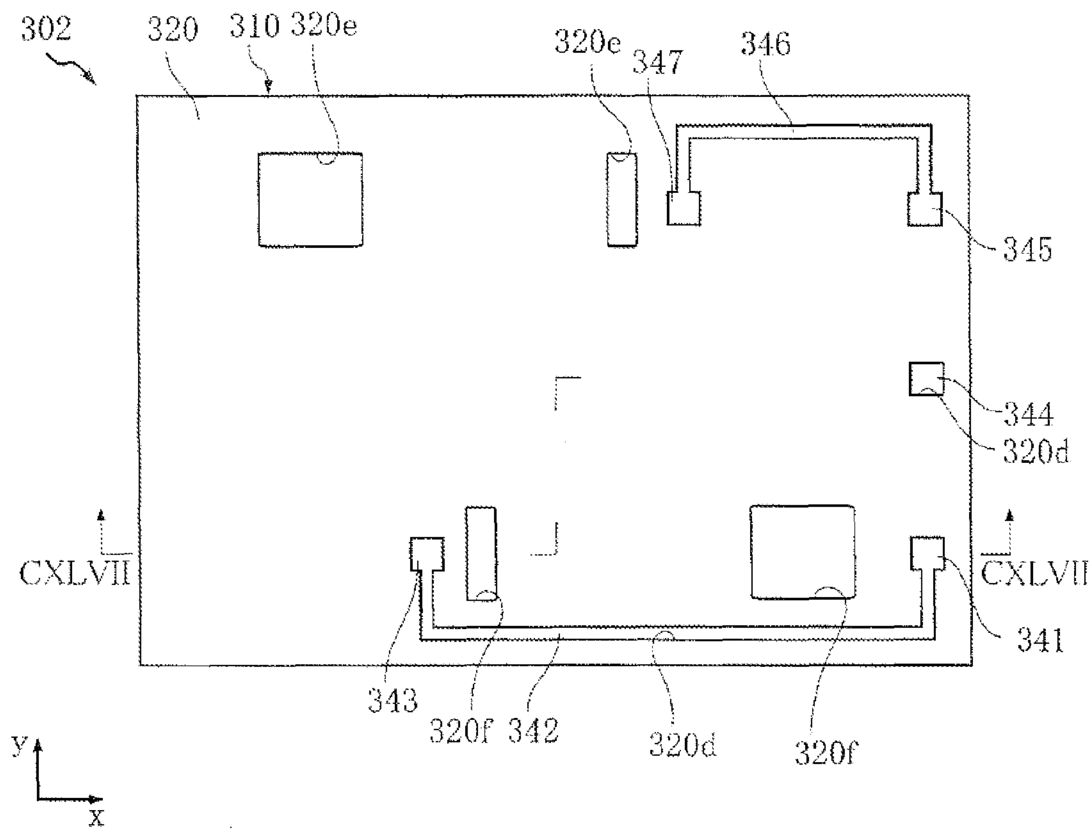
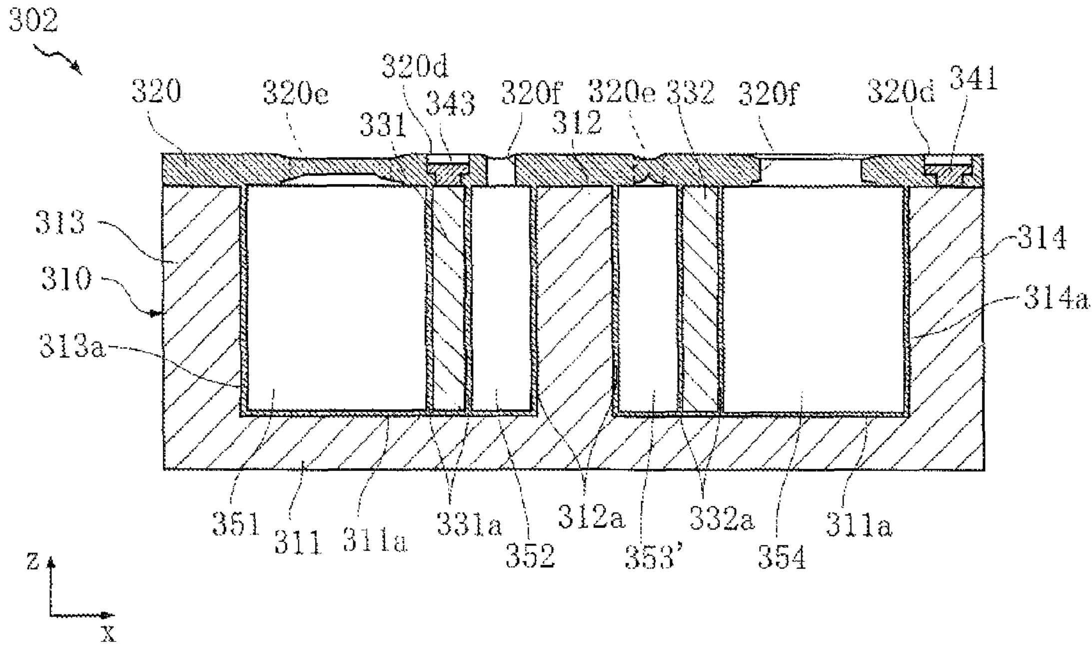

302
320
310
320e
320e
347
346
345
344
320d
CXLVII
CXLVII
341
343
320f
342
320d
320f
y
x

FIG.147



302
320
320e
320d
343
331
320f
312
320e
332
320f
320d
341
313
310
313a
314
314a
351
311
311a
331a
352
312a
353'
332a
354
311a
z
x

FIG.148

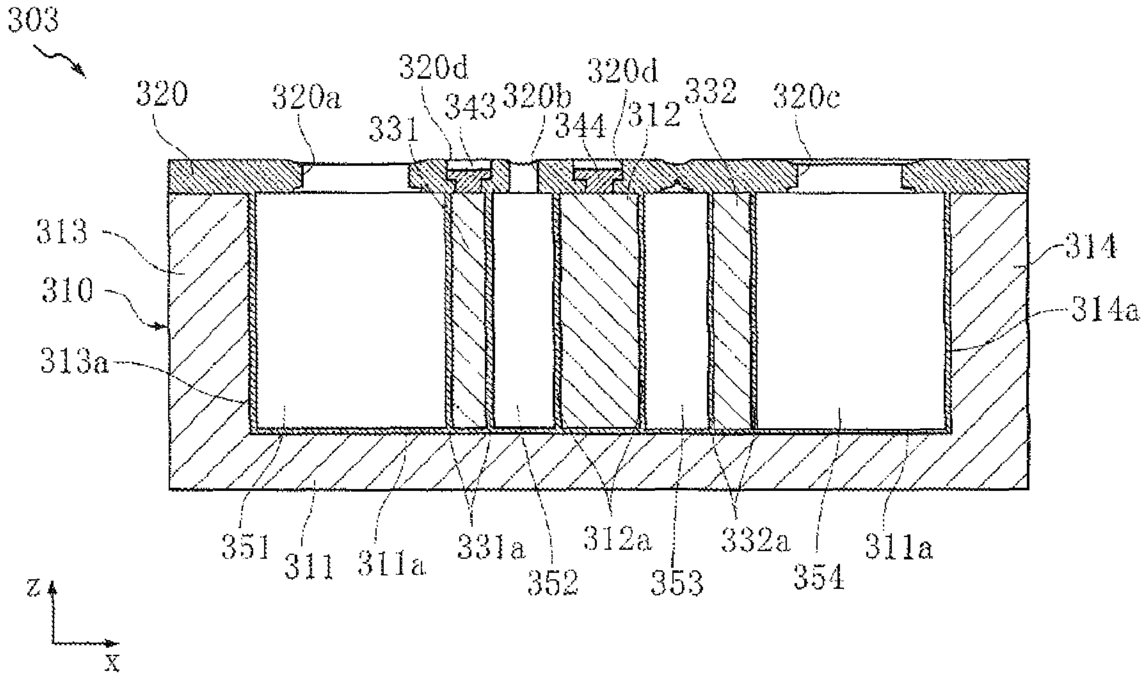


FIG.149

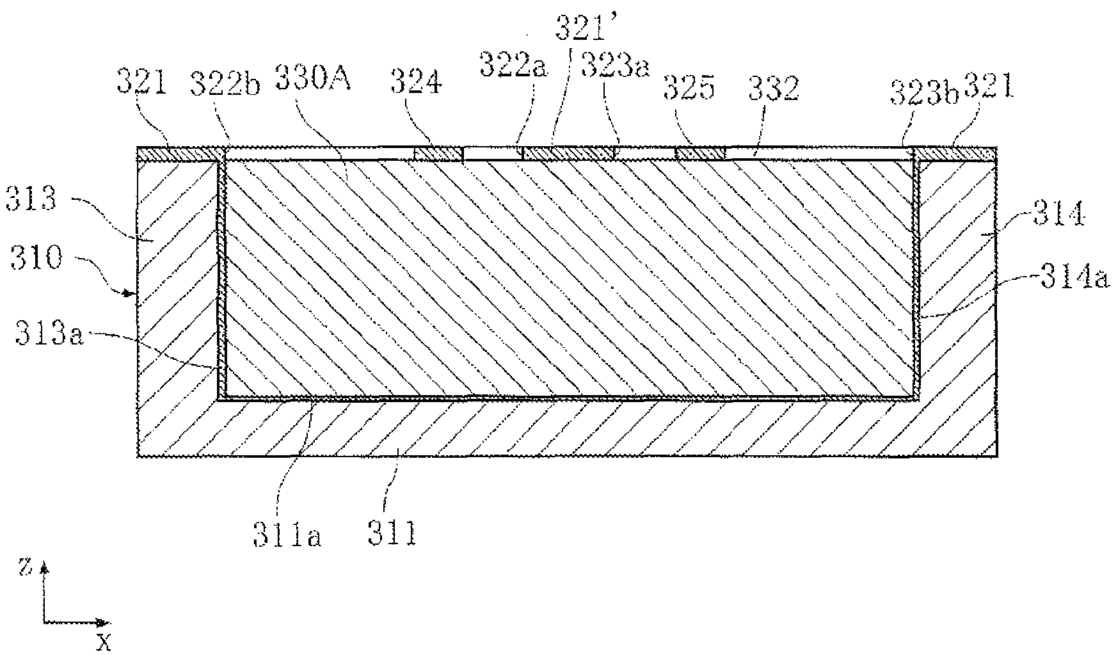


FIG.150

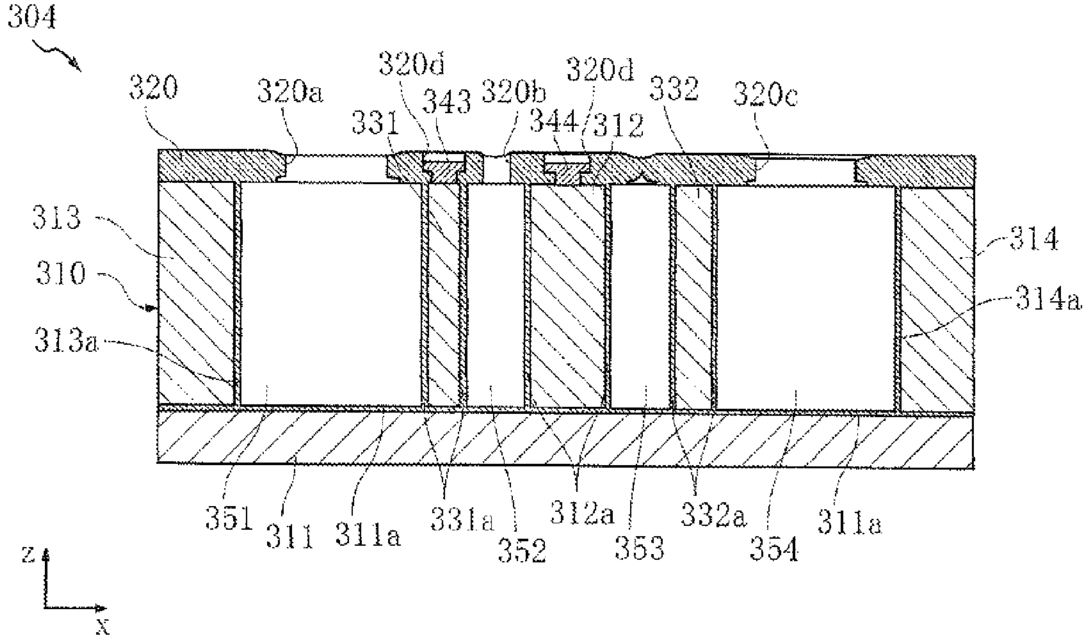


FIG.151

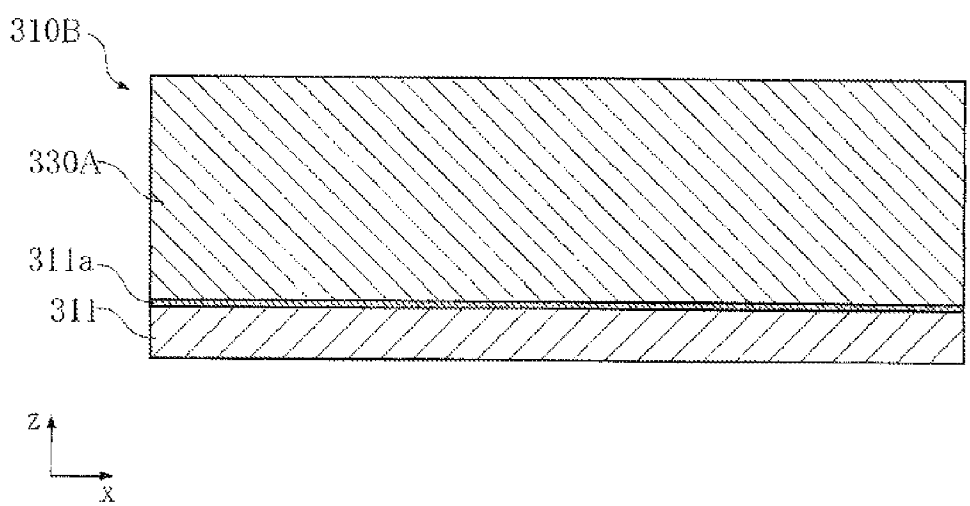


FIG.152

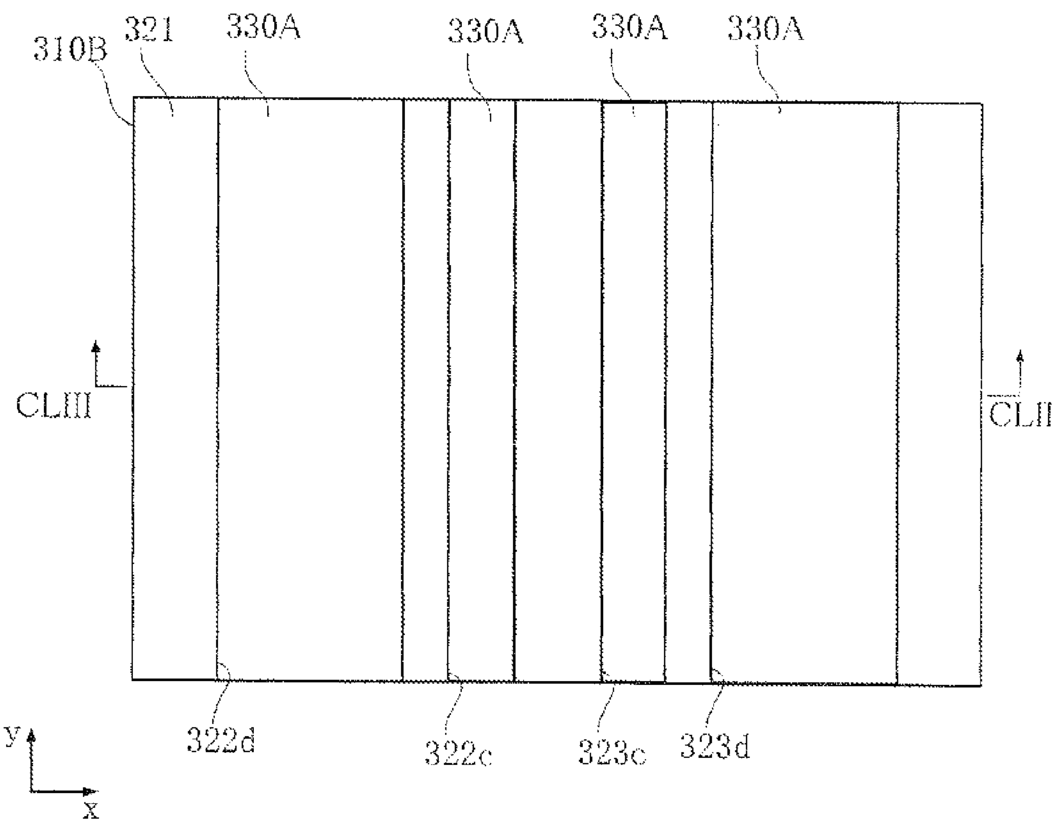

310B
321
330A
330A
330A
330A
CLIII
CLIII
322d
322c
323c
323d
y
x

FIG.153

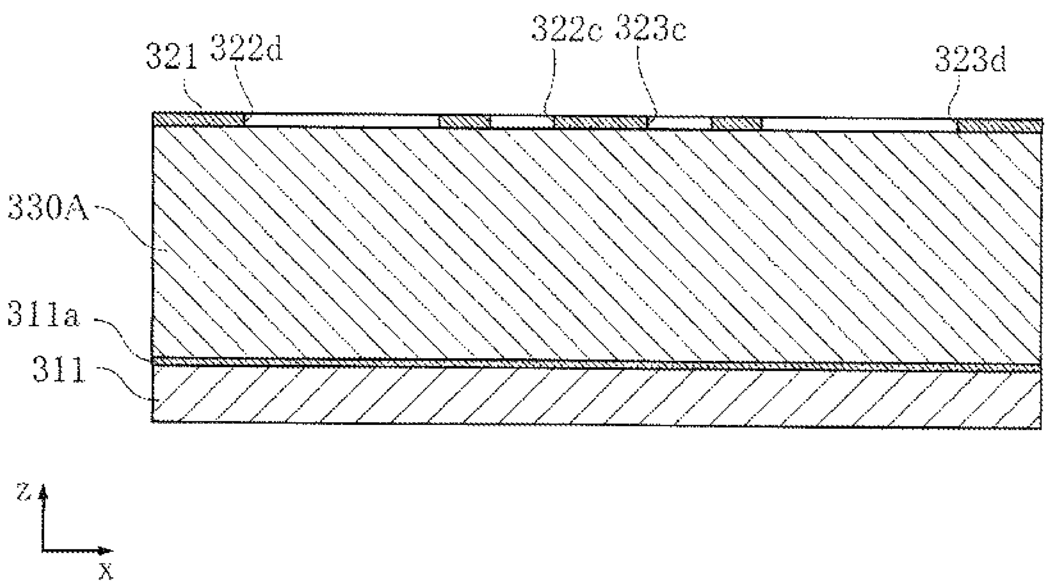


FIG.154
PRIOR ART

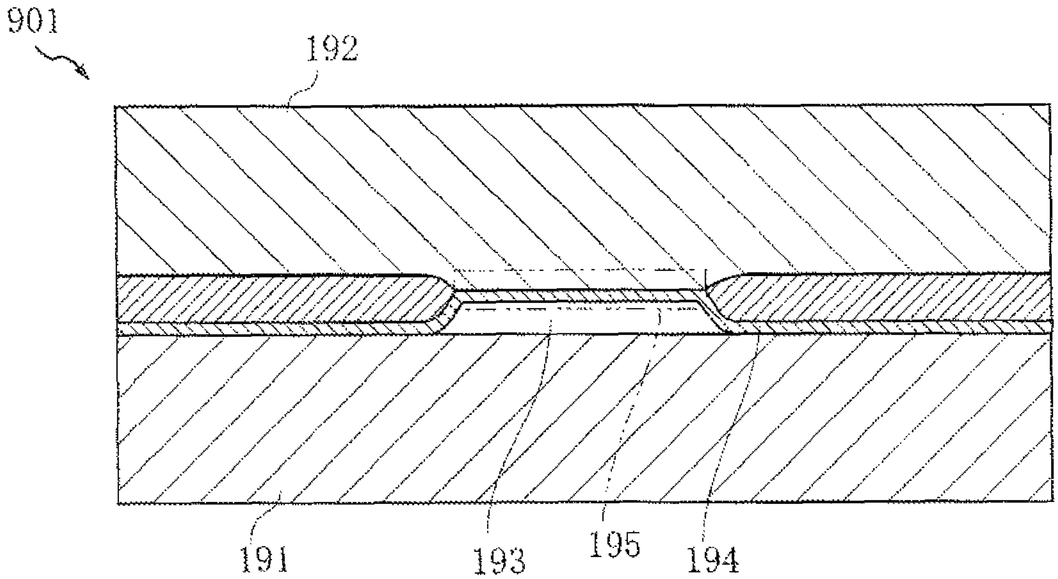
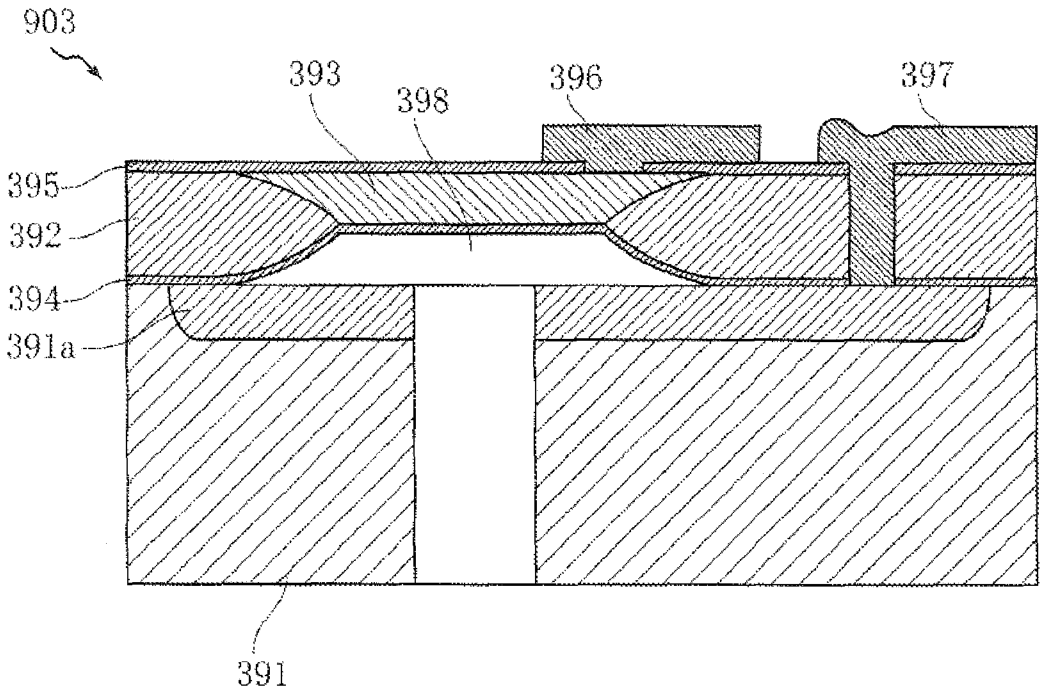


FIG.155
PRIOR ART



PRESSURE SENSOR AND METHOD FOR MANUFACTURING PRESSURE SENSOR

TECHNICAL FIELD

The present invention relates to a pressure sensor manufactured by a semiconductor manufacturing technique, and to a method for manufacturing such a pressure sensor.

BACKGROUND ART

FIG. **154** shows a process step of a method for manufacturing a conventional pressure sensor **901**, which is disclosed in Patent Document 1. As shown in FIG. **154**, to manufacture the pressure sensor **901**, two semiconductor substrates **191** and **192** are bonded together, with a cavity portion **193** and an insulating layer **194** intervening between the substrates. By subsequently abrading the semiconductor substrate **192**, a silicon diaphragm is provided on a portion **195** overlapping the cavity portion **193** in the vertical direction. The pressure sensor **901** detects changes in pressure by detecting changes in capacitance between the silicon diaphragm and the semiconductor substrate **191**.

However, as described above, to manufacture the pressure sensor **901**, two semiconductor substrates **191** and **192** need to be prepared and bonded together. Besides, processing to form a wiring and an electrode needs to be performed with respect to each of the semiconductor substrates **191** and **192**. Thus, the manufacturing process is complicated, resulting in a high manufacturing cost of the pressure sensor **901**.

FIG. **155** shows a conventional capacitive pressure sensor **903**, which is disclosed in Patent Document 1. As shown in FIG. **155**, the pressure sensor **903** includes a base substrate **391** in the form of a flat plate, an oxide film **392**, a movable electrode **393**, insulating layers **394**, **395**, metal wirings **396**, **397**, and a cavity portion **398**. The base substrate **391** is made of silicon and has a fixed electrode **391***a* on the surface, in which boron ions are implanted and dispersed. The movable electrode **393** is formed by implanting and dispersing boron ions into part of a material substrate of made of silicon, and then removing remaining portions. The movable electrode is supported by the oxide film **392**. The movable electrode **393** is formed to be parallel to the fixed electrode **391***a* by arranging the material substrate in parallel to the base substrate **391**. The insulating layer **394** provides insulation between the base substrate **391** and the oxide film **392**. The insulating layer **395** is formed to cover the surfaces of the oxide film **392** and movable electrode **393**. The cavity portion **398** is formed to separate the fixed electrode **391***a* and the movable electrode **393** in the direction normal to the surface of the base substrate **391** (lamination direction). The metal wiring **396** is electrically connected to the movable electrode **393**, and the metal wiring **397** is electrically connected to the fixed electrode **391***a*. This pressure sensor **903** detects changes in pressure by detecting changes in capacitance between the fixed electrode **391***a* and the movable electrode **393** facing each other in the lamination direction.

In recent years, size reduction of pressure sensors is increasingly demanded with size reduction of electronic devices. On the other hand, to detect changes in capacitance more precisely, it is desirable to increase the capacitance between the fixed electrode **391***a* and the movable electrode **393**, and for that purpose, the facing area of the fixed electrode **391***a* and the movable electrode **393** as viewed in the lamination direction of the base substrate **391** needs to be increased. Thus, it is difficult to reduce the area of the movable electrode **393** as viewed in the lamination direction, which hinders size reduction of the pressure sensor **903**.

Patent Document 1: Japanese Patent No. 2850558

DISCLOSURE OF THE INVENTION

Problems to be Solved by the Invention

The present invention has been proposed under the circumstances described above. It is therefore an object of the present invention to provide a more precise pressure sensor that can be manufactured easily. Another object of the present invention is to provide a method for manufacturing a pressure sensor that realizes size reduction.

Means for Solving the Problems

A pressure sensor provided according to a first aspect of the present invention comprises a semiconductor substrate, an insulating layer formed on the semiconductor substrate, a semiconductor layer formed on the semiconductor substrate, with the insulating layer intervening therebetween, and a cavity portion provided between the semiconductor substrate and the semiconductor layer. The portion of the semiconductor layer which overlaps the cavity portion as viewed in a lamination direction serves as a movable portion. The cavity portion is surrounded by the insulating layer.

In a preferred embodiment, the semiconductor substrate includes a recess extending inward in the lamination direction, and the cavity portion is provided in the recess.

In a preferred embodiment, the semiconductor layer is provided outside the recess.

In a preferred embodiment, the semiconductor layer is provided in the recess.

In a preferred embodiment, the pressure sensor further comprises a first electrode electrically connected to the semiconductor layer and a second electrode electrically connected to the semiconductor substrate.

In a preferred embodiment, the semiconductor substrate is made of single-crystal silicon, the semiconductor layer is made of polycrystalline silicon, and the insulating layer is made of silicon dioxide.

A method for manufacturing a pressure sensor according to a second aspect of the present invention comprises the steps of forming a recess in a semiconductor substrate, covering an entire surface of the recess with a first insulating layer, filling the recess with a sacrificial layer after covering the recess with the first insulating layer, covering with a second insulating layer a portion of the sacrificial layer which is exposed from the first insulating layer, forming a semiconductor layer to overlap the sacrificial layer with the second insulating layer intervening therebetween, and forming a cavity portion by removing the sacrificial layer. The portion of the semiconductor layer which overlaps the cavity portion serves as a movable portion.

A method for manufacturing a pressure sensor according to a third aspect of the present invention comprises the steps of forming a recess in a semiconductor substrate, covering an entire surface of the recess with a first insulating layer, forming a sacrificial layer to fill a portion of the recess which is close to a bottom after covering the recess with the first insulating layer, covering with a second insulating layer a portion of the sacrificial layer which is exposed from the first insulating layer, forming a semiconductor layer in the recess to overlap the sacrificial layer with the second insulating layer intervening therebetween, and forming a cavity portion by removing the sacrificial layer. The semiconductor layer serves as a movable portion.

A method for manufacturing a pressure sensor according to a fourth aspect of the present invention comprises the steps of forming a first insulating layer on a surface of a semiconductor substrate, forming a recess in the first insulating layer, forming a second insulating layer on a bottom of the recess, forming a sacrificial layer in the recess, covering with a third insulating layer a portion of the sacrificial layer which is exposed from the first insulating layer, forming a semiconductor layer to overlap the sacrificial layer with the third insulating layer intervening therebetween, and forming a cavity portion by removing the sacrificial layer. The portion of the semiconductor layer which overlaps the cavity portion serves as a movable portion.

In a preferred embodiment, the step of forming a cavity portion comprises forming a vent hole penetrating the semiconductor layer and reaching the sacrificial layer, etching the sacrificial layer through the vent hole, and sealing the vent hole with an insulating material after the sacrificial layer is removed.

A pressure sensor provided according to a fifth aspect of the present invention comprises a movable portion and a piezoresistor provided at the movable portion. The pressure sensor further comprises a semiconductor substrate including a cavity portion which is open at an obverse surface, a semiconductor layer formed on the obverse surface of the semiconductor substrate and including a through-hole penetrating in a lamination direction, and a sealing member which seals the through-hole. The portion of the semiconductor layer which overlaps the cavity portion as viewed in the lamination direction serves as the movable portion, and the through-hole is formed in the movable portion.

In a preferred embodiment, the sealing member seals the end of the through-hole on the obverse surface side of the semiconductor layer in the lamination direction.

In a preferred embodiment, the sealing member is made of a different material from the semiconductor layer.

In a preferred embodiment, the semiconductor layer is made of silicon, whereas the sealing member is made of silicon dioxide.

In a preferred embodiment, the pressure sensor further comprises an oxide film provided between the semiconductor layer and the semiconductor substrate.

In a preferred embodiment, the cavity portion is open at the reverse surface of the semiconductor substrate.

In a preferred embodiment, the piezoresistor is in the form of a strip including a bend.

In a preferred embodiment, the semiconductor substrate is provided with thirteen pairs of plate-like members projecting in the lamination direction and facing each other, and the movable portion and the cavity portion are sandwiched between the pair of plate-like members.

According to a sixth aspect of the present invention, there is provided a method for manufacturing a pressure sensor comprising a movable portion and a piezoresistor provided at the movable portion. The method comprises the steps of forming a semiconductor layer on an obverse surface side of a semiconductor substrate, forming a through-hole penetrating the semiconductor layer in a lamination direction and reaching the obverse surface of the semiconductor substrate, performing etching through the through-hole to form in the semiconductor substrate a cavity portion which is open at the obverse surface, and sealing the through-hole by filling a sealing member.

In a preferred embodiment, the semiconductor layer is made by using silicon, and the sealing member is made by using silicon dioxide.

In a preferred embodiment, the method further comprises the step of forming at a reverse surface of the semiconductor substrate an opening connected to the cavity portion.

In a preferred embodiment, the method further comprises the steps of forming a groove including a bend in the movable portion and forming a piezoresistor in the groove.

According to a seventh aspect of the present invention, there is provided a pressure sensor comprising a movable electrode and a fixed electrode arranged in parallel to each other. The pressure sensor further comprises a semiconductor substrate, a first insulating layer formed on the semiconductor substrate, a semiconductor layer formed on the semiconductor substrate with the first insulating layer intervening therebetween, a second insulating layer formed on the semiconductor layer, a first cavity portion formed in the semiconductor substrate, a second cavity portion overlapping the first cavity portion as viewed in a lamination direction and formed in contact with the second insulating layer. The fixed electrode faces the second insulating layer across the second cavity portion, and the movable electrode is provided at a portion of the semiconductor layer which is sandwiched between the first cavity portion and the second cavity portion.

In a preferred embodiment, the movable electrode includes a through-hole penetrating the semiconductor layer in the lamination direction, and the pressure sensor further comprises a sealing member which seals the through-hole.

In a preferred embodiment, the sealing member is made of a different material from the semiconductor layer.

In a preferred embodiment, the semiconductor layer is made of silicon, whereas the sealing member is made of silicon dioxide.

In a preferred embodiment, the pressure sensor further comprises a third insulating layer facing the second insulating layer across the second cavity portion. The fixed electrode is provided on the third insulating layer.

In a preferred embodiment, the pressure sensor further comprises a vent hole penetrating the fixed electrode in the lamination direction, and one end of the vent hole in the lamination direction reaches the second cavity portion.

In a preferred embodiment, the pressure sensor further comprises a movable electrode terminal electrically connected to the semiconductor layer.

In a preferred embodiment, the semiconductor substrate is provided with a pair of plate-like members projecting in the lamination direction and facing each other, and the movable electrode and the second cavity portion are sandwiched between the paired plate-like members.

In a preferred embodiment, the pressure sensor further comprises a protective layer formed on the paired plate-like members and including an opening which exposes the surface of at least one of the plate-like members, and a ground electrode terminal electrically connected to the semiconductor substrate via the opening.

According to an eighth embodiment of the present invention, there is provided a method for manufacturing a pressure sensor comprising a movable electrode and a fixed electrode arranged in parallel to each other. The method comprises the steps of forming a first insulating layer on a surface of a semiconductor substrate, forming a semiconductor layer on a surface of the first insulating layer, forming a recess in the semiconductor layer, forming a second insulating layer on a bottom surface of the recess, forming at a bottom of the recess a vent hole extending in a lamination direction and penetrating the second insulating layer, the semiconductor layer and the first insulating layer, performing etching through the vent hole to form a first cavity portion in the semiconductor substrate, sealing the through-hole, forming a sacrificial layer in the recess, forming a metal layer on the sacrificial layer, forming the fixed electrode from the metal layer, and removing the sacrificial layer to form a second cavity portion.

In a preferred embodiment, the method further comprises, between the step of forming a sacrificial layer in the recess and the step of forming a metal layer on the sacrificial layer, the steps of forming a third insulating layer on a surface of the sacrificial layer, and forming in the third insulating layer a through-hole penetrating in the lamination direction. The step of forming the fixed electrode from the metal layer comprises forming the fixed electrode to expose the through-hole. The step of removing the sacrificial layer to form a second cavity portion comprises etching the sacrificial layer through the through-hole.

In a preferred embodiment, the method for manufacturing a pressure sensor further comprises the step of forming a movable electrode terminal electrically connected to the semiconductor layer.

In a preferred embodiment, the method further comprises the step of processing the semiconductor substrate into a shape including a pair of plate-like members projecting from a surface in the lamination direction and facing each other. The step of forming a recess in the semiconductor layer comprises forming the recess in such a manner that the recess is sandwiched between the plate-like members in a direction in which the plate-like members face each other.

In a preferred embodiment, the step of processing into a shape including a pair of plate-like members comprises forming a protective layer to cover portions of the semiconductor substrate which correspond to the plate-like members as viewed in a lamination direction, and thinning in the lamination direction portions of the semiconductor substrate other than the portions covered with the protective layer. The method further comprises the steps of forming in the protective layer an opening which exposes part of the semiconductor substrate, and forming a ground electrode terminal electrically connected to the semiconductor substrate via the opening.

According to a ninth aspect of the present invention, there is provided a pressure sensor comprising a movable electrode and a fixed electrode arranged in parallel to each other. The pressure sensor further comprises a semiconductor substrate insulated from the movable electrode and supporting the movable electrode. The fixed electrode and the movable electrode face each other in an in-plane direction of the semiconductor substrate.

In a preferred embodiment, the movable electrode is made of a different material from the semiconductor substrate.

In a preferred embodiment, the fixed electrode is provided on a plate-like member projecting from the semiconductor substrate in a direction perpendicular to the in-plane direction.

In a preferred embodiment, the plate-like member comprises part of the semiconductor substrate.

In a preferred embodiment, the plate-like member is made of a same material as the movable electrode.

In a preferred embodiment, the pressure sensor further comprises, between the fixed electrode and the movable electrode in the in-plane direction, a closed space shut off from outside air.

In a preferred embodiment, the pressure sensor further comprises a wall portion standing from the semiconductor substrate. In the in-plane direction, the movable electrode is arranged between the wall portion and the fixed electrode such that the distance between the fixed electrode and the movable electrode is shorter than the distance between the movable electrode and the wall portion.

In a preferred embodiment, the wall portion comprises part of the semiconductor substrate.

In a preferred embodiment, the wall portion is made of a same material as the movable electrode.

In a preferred embodiment, the pressure sensor further comprises a gas supply space capable of taking in outside air. The gas supply space is provided between the movable electrode and the wall portion in the in-plane direction. The pressure sensor further comprises a closed space shut off from outside air. The closed space is provided between the fixed electrode and the movable electrode in the in-plane direction.

In a preferred embodiment, the pressure sensor further comprises a closed space shut off from outside air. The closed space is provided between the movable electrode and the wall portion in the in-plane direction. The pressure sensor further comprises a gas supply space capable of taking in outside air. The gas supply space is provided between the fixed electrode and the movable electrode in the in-plane direction.

In a preferred embodiment, the pressure sensor further comprises an additional movable electrode and an additional fixed electrode facing each other in the in-plane direction of the semiconductor substrate, and an additional wall portion standing from the semiconductor substrate. In the in-plane direction of the semiconductor substrate, the additional movable electrode is arranged between the additional wall portion and the additional fixed electrode such that the distance between the additional fixed electrode and the additional movable electrode is shorter than the distance between the additional movable electrode and the additional wall portion. An additional gas supply space capable of taking in outside air is provided between the additional movable electrode and the additional wall portion and between the additional fixed electrode and the additional movable electrode.

In a preferred embodiment, the pressure sensor further comprises an additional movable electrode and an additional fixed electrode facing each other in the in-plane direction of the semiconductor substrate, and an additional wall portion standing from the semiconductor substrate. In the in-plane direction of the semiconductor substrate, the additional movable electrode is arranged between the additional wall portion and the additional fixed electrode such that the distance between the additional fixed electrode and the additional movable electrode is shorter than the distance between the additional movable electrode and the additional wall portion. A closed space shut off from outside air is provided between the additional movable electrode and the additional wall portion and between the additional fixed electrode and the additional movable electrode.

In a preferred embodiment, the additional wall portion comprises part of the semiconductor substrate.

In a preferred embodiment, the wall portion, the additional movable electrode and the additional wall portion are made of a same material as the movable electrode.

In a preferred embodiment, the direction in which the additional movable electrode and the additional fixed electrode face each other is same as the direction in which the movable electrode and the fixed electrode face each other.

More preferably, the wall portion and the additional wall portion face each other in the direction in which the movable electrode and the fixed electrode face each other.

According to a tenth aspect of the present invention, there is provided a method for manufacturing a pressure sensor comprising a movable electrode and a fixed electrode arranged in parallel to each other. The method comprises the steps of performing etching in a first direction with respect to a semiconductor material, forming a fixed electrode including an electrode surface perpendicular to a second direction crossing the first direction at right angles, and forming a movable electrode including an electrode surface facing the electrode surface of the fixed electrode in the second direction.

In a preferred embodiment, the step of forming a movable electrode comprises forming a semiconductor layer on a remaining portion of the semiconductor material and performing etching in the first direction with respect to the semiconductor layer. The movable electrode is formed as a remaining portion of the semiconductor layer.

In a preferred embodiment, the fixed electrode is formed as a remaining portion of the semiconductor material in the step of performing etching with respect to the semiconductor material.

In another preferred embodiment, the fixed electrode is formed as a remaining portion of the semiconductor layer in the step of performing etching with respect to the semiconductor layer.

In a preferred embodiment, the step of performing etching with respect to the semiconductor material comprises forming a wall portion including a side surface facing the electrode surface of the fixed electrode in the second direction, as a remaining portion of the semiconductor material. The step of forming a movable electrode comprises forming a movable electrode between the wall portion and the fixed electrode in the second direction at a position closer to the fixed electrode than to the wall portion.

In another preferred embodiment, the semiconductor material comprises a semiconductor substrate and a semiconductor layer formed on the semiconductor substrate. The step of performing etching with respect to the semiconductor material comprises performing etching with respect to the semiconductor layer to form the fixed electrode and the movable electrode as a remaining portion of the semiconductor layer.

In a preferred embodiment, the step of performing etching with respect to the semiconductor material comprises forming a wall portion including a side surface facing the electrode surface of the fixed electrode in the second direction, as a remaining portion of the semiconductor layer. The movable electrode is formed between the wall portion and the fixed electrode in the second direction at a position closer to the fixed electrode than to the wall portion.

Other features and advantages of the present invention will become more apparent from the detailed description given below with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a plan view showing a pressure sensor according to a first embodiment of the present invention;

FIG. **2** is a sectional view taken along lines II-II in FIG. **1**;

FIG. **3** is a sectional view showing a step of a method for manufacturing the pressure sensor shown in FIG. **2**;

FIG. **4** is a sectional view showing a step subsequent to the step of FIG. **3**;

FIG. **5** is a sectional view showing a step subsequent to the step of FIG. **4**;

FIG. **6** is a sectional view showing a step subsequent to the step of FIG. **5**;

FIG. **7** is a sectional view showing a step subsequent to the step of FIG. **6**;

FIG. **8** is a sectional view showing a step subsequent to the step of FIG. **7**;

FIG. **9** is a sectional view showing a step subsequent to the step of FIG. **8**

FIG. **10** is a sectional view showing a step subsequent to the step of FIG. **9**;

FIG. **11** is a sectional view showing a step subsequent to the step of FIG. **10**;

FIG. **12** is a sectional view showing a step subsequent to the step of FIG. **11**;

FIG. **13** is a sectional view showing a step subsequent to the step of FIG. **12**;

FIG. **14** is a sectional view showing a step subsequent to the step of FIG. **13**;

FIG. **15** is a sectional view showing a step subsequent to the step of FIG. **14**;

FIG. **16** is a sectional view showing a step subsequent to the step of FIG. **15**;

FIG. **17** is a sectional view showing a step subsequent to the step of FIG. **16**;

FIG. **18** is a sectional view showing a step subsequent to the step of FIG. **17**;

FIG. **19** is a plan view showing a pressure sensor according to a second embodiment of the present invention;

FIG. **20** is a sectional view taken along lines XX-XX in FIG. **19**;

FIG. **21** is a sectional view showing a step of a method for manufacturing the pressure sensor shown in FIG. **20**;

FIG. **22** is a sectional view showing a step subsequent to the step of FIG. **21**;

FIG. **23** is a sectional view showing a step subsequent to the step of FIG. **22**;

FIG. **24** is a sectional view showing a step subsequent to the step of FIG. **23**;

FIG. **25** is a sectional view showing a step subsequent to the step of FIG. **24**;

FIG. **26** is a sectional view showing a step subsequent to the step of FIG. **25**;

FIG. **27** is a sectional view showing a step subsequent to the step of FIG. **26**;

FIG. **28** is a sectional view showing a step subsequent to the step of FIG. **27**;

FIG. **29** is a sectional view showing a step subsequent to the step of FIG. **28**;

FIG. **30** is a sectional view showing a step subsequent to the step of FIG. **29**;

FIG. **31** is a sectional view showing a step subsequent to the step of FIG. **30**;

FIG. **32** is a sectional view showing a step subsequent to the step of FIG. **31**;

FIG. **33** is a sectional view showing a step subsequent to the step of FIG. **32**;

FIG. **34** is a sectional view showing a step subsequent to the step of FIG. **33**;

FIG. **35** is a sectional view showing a step subsequent to the step of FIG. **34**;

FIG. **36** is a plan view showing a pressure sensor according to a third embodiment of the present invention;

FIG. **37** is a sectional view taken along lines XXXVII-XXXVII in FIG. **36**;

FIG. **38** is a sectional view showing a step of a method for manufacturing the pressure sensor shown in FIG. **37**;

FIG. **39** is a sectional view showing a step subsequent to the step of FIG. **38**;

FIG. **40** is a sectional view showing a step subsequent to the step of FIG. **39**;

FIG. **41** is a sectional view showing a step subsequent to the step of FIG. **40**;

FIG. **42** is a sectional view showing a step subsequent to the step of FIG. **41**;

FIG. **43** is a sectional view showing a step subsequent to the step of FIG. **42**;

FIG. **44** is a sectional view showing a step subsequent to the step of FIG. **43**;

FIG. **45** is a sectional view showing a step subsequent to the step of FIG. **44**;

FIG. **46** is a sectional view showing a step subsequent to the step of FIG. **45**;

FIG. **47** is a sectional view showing a step subsequent to the step of FIG. **46**;

FIG. **48** is a sectional view showing a step subsequent to the step of FIG. **47**;

FIG. **49** is a sectional view showing a step subsequent to the step of FIG. **48**;

FIG. **50** is a sectional view showing a step subsequent to the step of FIG. **49**;

FIG. **51** is a sectional view showing a step subsequent to the step of FIG. **50**;

FIG. **52** is a sectional view showing a step subsequent to the step of FIG. **51**;

FIG. **53** is a sectional view showing a step subsequent to the step of FIG. **52**;

FIG. **54** is a plan view showing a pressure sensor according to a fourth embodiment of the present invention;

FIG. **55** is a sectional view taken along lines LV-LV in FIG. **54**;

FIG. **56** is a sectional view showing a step of a method for manufacturing the pressure sensor shown in FIG. **55**;

FIG. **57** is a plan view showing a step subsequent to the step of FIG. **56**;

FIG. **58** is a sectional view taken along lines LVIII-LVIII in FIG. **57**;

FIG. **59** is a sectional view showing a step subsequent to the step of FIG. **58**;

FIG. **60** is a sectional view showing a step subsequent to the step of FIG. **59**;

FIG. **61** is a sectional view showing a step subsequent to the step of FIG. **60**;

FIG. **62** is a plan view showing a step subsequent to the step of FIG. **61**;

FIG. **63** is a sectional view taken along lines LXIII-LXIII in FIG. **62**;

FIG. **64** is a sectional view showing a step subsequent to the step of FIG. **63**;

FIG. **65** is a sectional view showing a step subsequent to the step of FIG. **64**;

FIG. **66** is a plan view showing a step subsequent to the step of FIG. **65**;

FIG. **67** is a sectional view taken along lines LXVII-LXVII in FIG. **66**;

FIG. **68** is a plan view showing a step subsequent to the step of FIG. **67**;

FIG. **69** is a sectional view taken along lines LXIX-LXIX in FIG. **68**;

FIG. **70** is a plan view showing a pressure sensor according to a fifth embodiment of the present invention;

FIG. **71** is a sectional view taken along lines LXXI-LXXI in FIG. **70**;

FIG. **72** is a plan view showing a step of a method for manufacturing the pressure sensor shown in FIG. **70**;

FIG. **73** is a sectional view taken along lines LXXIII-LXXIII in FIG. **72**;

FIG. **74** is a sectional view showing a pressure sensor according to a sixth embodiment of the present invention;

FIG. **75** is a plan view showing a pressure sensor according to a seventh embodiment of the present invention;

FIG. **76** is a sectional view taken along lines LXXVI-LXXVI in FIG. **75**;

FIG. **77** is a plan view showing a step of a method for manufacturing the pressure sensor shown in FIG. **75**;

FIG. **78** is a sectional view taken along lines LXXVIII-LXXVIII in FIG. **77**;

FIG. **79** is a sectional view showing a step subsequent to the step of FIG. **78**;

FIG. **80** is a sectional view showing a step subsequent to the step of FIG. **79**;

FIG. **81** is a sectional view showing a step subsequent to the step of FIG. **80**;

FIG. **82** is a plan view showing a step subsequent to the step of FIG. **81**;

FIG. **83** is a sectional view taken along lines LXXXIII-LXXXIII in FIG. **82**;

FIG. **84** is a plan view showing a step subsequent to the step of FIG. **82**;

FIG. **85** is a sectional view taken along lines LXXXV-LXXXV in FIG. **84**;

FIG. **86** is a plan view showing a pressure sensor according to an eighth embodiment of the present invention;

FIG. **87** is a sectional view taken along lines LXXXVII-LXXXVII in FIG. **86**;

FIG. **88** is a sectional view showing a step subsequent to the step of FIG. **87**;

FIG. **89** is a plan view showing a step subsequent to the step of FIG. **88**;

FIG. **90** is a sectional view taken along lines XC-XC in FIG. **89**;

FIG. **91** is a sectional view showing a step subsequent to the step of FIG. **90**;

FIG. **92** is a sectional view showing a step subsequent to the step of FIG. **91**;

FIG. **93** is a plan view showing a step subsequent to the step of FIG. **92**;

FIG. **94** is a sectional view taken along lines XCIV-XCIV in FIG. **93**;

FIG. **95** is a sectional view showing a step subsequent to the step of FIG. **94**;

FIG. **96** is a sectional view showing a step subsequent to the step of FIG. **95**;

FIG. **97** is a sectional view showing a step subsequent to the step of FIG. **96**;

FIG. **98** is a sectional view showing a step subsequent to the step of FIG. **97**;

FIG. **99** is a sectional view showing a step subsequent to the step of FIG. **98**;

FIG. **100** is a sectional view showing a step subsequent to the step of FIG. **99**;

FIG. **101** is a sectional view showing a step subsequent to the step of FIG. **100**;

FIG. **102** is a plan view showing a step subsequent to the step of FIG. **101**;

FIG. **103** is a sectional view taken along lines CIII-CIII in FIG. **102**;

FIG. **104** is a sectional view showing a step subsequent to the step of FIG. **103**;

FIG. **105** is a plan view showing a step subsequent to the step of FIG. **104**;

FIG. **106** is a sectional view taken along lines CVI-CVI in FIG. **105**;

FIG. **107** is a sectional view showing a pressure sensor according to a ninth embodiment of the present invention;

FIG. **108** is a sectional view showing a pressure sensor according to a tenth embodiment of the present invention;

FIG. **109** is a plan view showing a pressure sensor according to an eleventh embodiment of the present invention;

FIG. **110** is a sectional view taken along lines CX-CX in FIG. **109**;

FIG. **111** is a plan view showing a step of a method for manufacturing the pressure sensor shown in FIG. **110**;

FIG. **112** is a sectional view taken along lines CXII-CXII in FIG. **111**;

FIG. **113** is a sectional view showing a step subsequent to the step of FIG. **112**;

FIG. **114** is a sectional view showing a step subsequent to the step of FIG. **113**;

FIG. **115** is a sectional view showing a step subsequent to the step of FIG. **114**;

FIG. **116** is a sectional view showing a step subsequent to the step of FIG. **115**;

FIG. **117** is a sectional view showing a step subsequent to the step of FIG. **116**;

FIG. **118** is a sectional view taken along lines CXVIII-CXVIII in FIG. **117**;

FIG. **119** is a sectional view showing the state after the steps shown in FIGS. **91-101** are performed after the step of FIG. **118**;

FIG. **120** is a plan view showing a step performed after the state of FIG. **119** is obtained;

FIG. **121** is a sectional view taken along lines CXXI-CXXI in FIG. **120**;

FIG. **122** is a sectional view showing a step subsequent to the step of FIG. **121**;

FIG. **123** is a plan view showing a step subsequent to the step of FIG. **122**;

FIG. **124** is a sectional view taken along lines CXXIV-CXXIV in FIG. **123**;

FIG. **125** is a plan view showing a pressure sensor according to a twelfth embodiment of the present invention;

FIG. **126** is a sectional view taken along lines CXXVI-CXXVI in FIG. **125**;

FIG. **127** is a plan view showing a step of a method for manufacturing the pressure sensor shown in FIG. **126**;

FIG. **128** is a sectional view taken along lines CXXVIII-CXXVIII in FIG. **127**;

FIG. **129** is a sectional view showing a step subsequent to the step of FIG. **128**;

FIG. **130** is a sectional view showing a step subsequent to the step of FIG. **129**;

FIG. **131** is a sectional view showing a step subsequent to the step of FIG. **130**;

FIG. **132** is a sectional view showing a step subsequent to the step of FIG. **131**;

FIG. **133** is a plan view showing a step subsequent to the step of FIG. **132**;

FIG. **134** is a sectional view taken along lines CXXXIV-CXXXIV in FIG. **133**;

FIG. **135** is a sectional view showing a step subsequent to the step of FIG. **134**;

FIG. **136** is a sectional view showing a step subsequent to the step of FIG. **135**;

FIG. **137** is a sectional view showing a step subsequent to the step of FIG. **136**;

FIG. **138** is a sectional view showing a step subsequent to the step of FIG. **137**;

FIG. **139** is a plan view showing a step subsequent to the step of FIG. **138**;

FIG. **140** is a sectional view taken along lines CXL-CXL in FIG. **139**;

FIG. **141** is a sectional view showing a step subsequent to the step of FIG. **140**;

FIG. **142** is a sectional view showing a step subsequent to the step of FIG. **141**;

FIG. **143** is a sectional view taken along lines CXLIII-CXLIII in FIG. **142**;

FIG. **144** is a sectional view showing a step subsequent to the step of FIG. **143**;

FIG. **145** is a sectional view showing a step subsequent to the step of FIG. **144**;

FIG. **146** is a plan view showing a pressure sensor according to a thirteenth embodiment of the present invention;

FIG. **147** is a sectional view taken along lines CXLVII-CXLVII in FIG. **146**;

FIG. **148** is a sectional view showing a pressure sensor according to a thirteenth embodiment of the present invention;

FIG. **149** is a sectional view showing a step of a method for manufacturing the pressure sensor shown in FIG. **148**;

FIG. **150** is a sectional view showing a pressure sensor according to a fifteenth embodiment of the present invention;

FIG. **151** is a sectional view showing a semiconductor material for the pressure sensor shown in FIG. **150**;

FIG. **152** is a plan view showing a step of a method for manufacturing the pressure sensor shown in FIG. **150**;

FIG. **153** is a sectional view taken along lines CLIII-CLIII in FIG. **152**;

FIG. **154** is a sectional view showing an example of a method for manufacturing a conventional pressure sensor; and

FIG. **155** is a sectional view showing an example of a conventional pressure sensor.

BEST MODE FOR CARRYING OUT THE INVENTION

Preferred embodiments of the present invention are described below with reference to the accompanying drawings.

FIGS. **1** and **2** show a pressure sensor according to a first embodiment of the present invention. The pressure sensor **1** of this embodiment comprises a semiconductor substrate **10**, and an insulating layer **20** and a semiconductor layer **30** formed on the semiconductor substrate. The pressure sensor is provided with a cavity portion **13**, a movable portion **31** and electrodes **51**, **52**.

The semiconductor substrate **10** is e.g. a single-crystal silicon (Si) substrate and has a recess **11** extending inward in the lamination direction (vertical direction in FIG. **2**) at the center. The cavity portion **13** is defined in the recess **11**. The cavity portion **13** is in a vacuum state. The dimension of the cavity portion **13** in the vertical direction is e.g. 1 to 5 μm, and that in the horizontal direction is e.g. 100 to 500 μm.

The semiconductor layer **30** is made of e.g. polycrystalline silicon. The semiconductor layer **30** has a thickness of e.g. 2 to 10 μm. The semiconductor layer **30** is formed over the substantially entire surface of the semiconductor substrate **10**, except the right end in FIG. **2**. It is to be noted that the semiconductor layer **30** is not provided at portions corresponding to vent holes formed in the manufacturing process, which will be described later.

The insulating layer **20** is made of e.g. silicon dioxide (SiO_2). The insulating layer **20** is made up of insulating layers **21**, **22**, **23**, **27**, which are made in different steps in the manufacturing process, as will be described later.

The insulating layer **21** provides insulation between the semiconductor layer **30** and the semiconductor substrate **10** at portions where the recess **11** is not formed. The thickness of the insulating layer **21** is e.g. 0.3 to 2.0 μm. The insulating layer **22** covers the surface of the recess **11**. The thickness of the insulating layer **22** is e.g. 0.3 to 2.0 μm. The insulating layer **23** covers the lower surface of the semiconductor layer **30** which faces the cavity portion **13**. The thickness of the insulating layer **23** is e.g. 0.3 to 2.0 μm. The insulating layer **27** covers the semiconductor layer **30** and the right end in FIG. **2** of the surface of the semiconductor substrate **10**. The thickness of the insulating layer **27** on the semiconductor layer **30** is e.g. 0.3 to 2.0 μm. The insulating layer **27** includes a plurality of sealing portions **27***a* which seal the portions corresponding to vent holes **13**A formed in the manufacturing process, which will be described later. The sealing portions **27***a* are concave relative to the surrounding portions. The sealing portions **27***a* can be made flat by performing CMP (chemical mechanical polishing). The insulating layer **27** has a through-hole **27***b* penetrating in the lamination direction at the left end in FIG. **27** and a through-hole **27***c* penetrating in the lamination direction at the right end in FIG. **27**.

The electrode **51** is formed to be electrically connected to the semiconductor layer **30** via the through-hole **27***b*. The electrode **52** is formed to be electrically connected to the semiconductor substrate **10** via the through-hole **27***c*.

The movable portion **31** comprises a portion of the semiconductor layer **30** which overlaps the cavity portion **13** in the lamination direction, and the insulating layers **23**, **27** on and under this portion of the semiconductor layer. The movable portion **31** is movable up and down in the lamination direction.

A method for manufacturing the pressure sensor **1** is described below with reference to FIGS. **3**-**18**.

First, a semiconductor substrate **10** made of single-crystal silicon is prepared. Specifically, a semiconductor substrate **10** having a thickness of 300 to 700 μm is prepared. In the next step, as shown in FIG. **3**, an insulating layer **21** of SiO_2 is formed on the surface of the semiconductor substrate **10**. This step can be performed by thermally oxidizing the surface of the semiconductor substrate **10**.

In the next step, as shown in FIG. **4**, an opening **21***a* for exposing the surface of the semiconductor substrate **10** is formed in the insulating layer **21**. This step is performed by providing a resist of resin which exposes the portion where the opening **21***a* is to be formed and performing wet etching using aqueous solution of hydrogen fluoride.

In the next step, a recess **11** is formed in the semiconductor substrate **10**, as shown in FIG. **5**. This step can be performed by gas-phase etching using gas containing atomic fluorine (F). F reacts with silicon (Si) but does not react with SiO_2. Thus, the insulating layer **21** is not etched away, but the semiconductor substrate **10** is etched away at the portion exposed through the opening **21***a*, whereby the recess **11** is formed. In this step, by adjusting the time of dry etching, the recess **11** of a desired depth can be formed. The gas containing F can be obtained by decomposing carbon tetrafluoride (CF_4) gas or sulfur hexafluoride (SF_6) gas by discharge.

In the next step, an insulating layer **22** is formed, as shown in FIG. **6**. This step can be performed by thermally oxidizing the surface of the recess **11**.

In the next step, as shown in FIG. **7**, a sacrificial layer **12** is formed in the recess **11**. The sacrificial layer **12** is a layer of polycrystalline silicon. This step is performed by e.g. embedding polycrystalline silicon in the recess **11**. The polycrystalline silicon to be embedded in the recess **11** is processed in advance such that the surface of the sacrificial layer **12** is flush with the surface of the insulating layer **21**. Alternatively, the polycrystalline silicon may be abraded after being embedded in the recess such that the surface of the sacrificial layer **12** is flush with the surface of the insulating layer **21**.

In the next step, an insulating layer **23** of SiO_2 is formed, as shown in FIG. **8**. This step can be performed by thermally oxidizing the surface of the sacrificial layer **12**.

In the next step, a semiconductor layer **30** is formed, as shown in FIG. **9**. This step can be performed by causing polycrystalline silicon to grow on the surfaces of the insulating layer **21**, **23** by e.g. chemical vapor deposition (CVD).

In the next step, an insulating layer **24** of SiO_2 is formed on the surface of the semiconductor layer **30**, as shown in FIG. **10**. For instance, this step can be performed by thermally oxidizing the surface of the semiconductor layer **30**.

In the next step, a plurality of through-holes **24***a* are formed in the insulating layer **24**, as shown in FIG. **11**. At the same time, in this step, the right end in the figure of the insulating layer **24** is removed to expose the right end of the semiconductor layer **30**. This step can be performed by gas-phase etching using the reaction between fluorine-containing molecular ions (HF_2^-) and SiO_2. HF_2^- can be obtained by reacting hydrogen fluoride (HF) with water vapor. HF can be obtained by reacting F or molecular fluorine (F_2), which is obtained by e.g. decomposing CF_4 gas or SF_6 gas, with water vapor. Since Si which is not oxidized does not easily react with HF_2^-, the semiconductor layer **30** is not removed by the etching and hence remains.

In the next step, as shown in FIG. **12**, a plurality of through-holes **30***a* are formed in the semiconductor layer **30** so that each of the through-holes **30***a* is connected to a respective one of the through-holes **24***a* at the upper end and reaches the insulating layer **23** at the lower end. This step can be performed by gas-phase etching using gas containing HF. The gas containing HF can be prepared by e.g. decomposing by discharge a gas obtained by adding water vapor to CF_4 gas or SF_6 gas. By performing etching while keeping HF in a dry state and suppressing generation of HF_2^-, SiO_2 is prevented from being etched away. In this step, therefore, the insulating layers **23** and **24** remain. Further, in this step, the right end of the semiconductor layer **30** is removed, so that the insulating layer **21***b*, which is the right end portion of the insulating layer **21**, is exposed.

In the next step, insulating layers **25** and **26** of SiO_2 are formed, as shown in FIG. **13**. The insulating layer **25** is formed on the inner circumferential surface of each of the through-holes **30***a*. The insulating layer **26** is formed on the semiconductor layer **30** at the portion that is not covered with the insulating layer **21**, **24**. This step is performed by thermally oxidizing the portion of the semiconductor layer **30** which is not covered with the insulating layer **21**, **24**.

In the next step, a resist **40** is applied, as shown in FIG. **14**. The resist **40** is made of e.g. resin and covers the insulating layer **24** and the insulating layer **21***b* but does not cover the through-holes **24***a*. This step is performed by applying liquefied resin to the surfaces of the insulating layer **24** and the insulating layer **21***b*.

In the next step, vent holes **13**A are formed, as shown in FIG. **15**. The vent holes **13**A are made by forming through-holes **23***a* in the insulating layer **23** such that each of the through-holes **23***a* is connected to one of the through-holes **24***a* and one of the through-hole **30***a*. This step can be performed by gas-phase etching using the reaction between HF_2^- and SiO_2. In this step, after the vent holes **13**A are formed, the resist **40** is removed.

In the next step, a cavity portion **13** is formed by removing the sacrificial layer **12**, as shown in FIG. **16**. The removal of the sacrificial layer **12** is performed by gas-phase etching, i.e., sending gas containing F to the sacrificial layer **12** through the vent holes **13**A. F can be obtained by e.g. decomposing CF_4 gas or SF_6 gas. Since F does not easily react with SiO_2, the insulating layers **21**, **22**, **23**, **24**, **25**, **26** remain in this step, and the semiconductor substrate **10** and the semiconductor layer **30** protected by these insulating layers also remain. By forming the cavity portion **13** in this way, the portion of the semiconductor layer **30** which overlaps the cavity portion **13** as viewed in the lamination direction and the insulating layers **23**, **24** on and under this portion become the movable portion **31**.

In the next step, an insulating layer **27** and sealing portions **27***a* are formed, as shown in FIG. **17**. In this step, for instance, plasma CVD is performed in a vacuum atmosphere. In this step, SiO_2 is further deposited on the insulating layers **21***b*, **24**, **25**, **26**. As a result of deposition of SiO_2 on the insulating layer **25**, the vent holes **13**A are sealed to become sealing portions **27***a*. As a result of deposition of SiO_2 on the insulating layers **21***b*, **24**, **26**, the insulating layer **27** is provided.

In the next step, through-holes **27***b* and **27***c* are formed, as shown in FIG. **18**. Specifically, the through-holes **27***b* and **27***c* are formed by providing a resist of resin such that the portions where the through-holes **27***b* and **27***c* are to be formed are exposed and performing wet etching using aqueous solution of hydrogen fluoride or gas-phase etching using the reaction between HF_2^- and SiO_2. The through-hole **27***b* reaches the semiconductor layer **30**, and the through-hole **27***c* reaches the semiconductor substrate **10**.

After the above-described steps, electrodes **51** and **52** are provided, whereby the pressure sensor **1** shown in FIGS. **1** and **2** is completed. For instance, the electrodes **51** and **52** are provided by forming an aluminum (Al) layer in the through-holes **27***b*, **27***c* and on the insulating layer **27** and removing unnecessary portions of the Al layer by etching.

The operation and advantages of the pressure sensor **1** are described below.

According to this embodiment, when the movable portion **31** moves up and down, the capacitance between the semiconductor substrate **10** and the semiconductor layer **30** changes. The pressure sensor **1** detects such changes in capacitance between the semiconductor substrate **10** and the semiconductor layer **30** to detect changes in pressure applied to the movable portion **31**. Since the cavity portion **13** is in a vacuum state, the pressure sensor **1** is suitable for measuring e.g. the absolute pressure applied to the movable portion **31**.

According to the present invention, the cavity portion **13** is surrounded by the insulating layers **22** and **23**. Thus, in the pressure sensor **1**, the capacitance between the semiconductor substrate **10** and the semiconductor layer **30** is relatively large. A larger capacitance between the semiconductor substrate **10** and the semiconductor layer **30** allows more sensitive detection of changes in the capacitance. Thus, the pressure sensor **1** ensures more precise pressure measurement.

Further, according to this embodiment, the recess **11** is formed by etching, and the bottom of the recess **11** is made parallel to the surface of the semiconductor substrate **10**. Further, the semiconductor layer **30** is formed on the insulating layer **21** formed by oxidizing the surface of the semiconductor substrate **10** and on the insulating layer **23** formed to conform to the insulating substrate **21**. Accordingly, in the pressure sensor **1**, the bottom surface of the recess **11** and the semiconductor layer **30** are parallel to each other, with the cavity portion **13** intervening between them. This arrangement allows the capacitance between the semiconductor substrate **10** and the semiconductor layer **30** to be set precisely to a predetermined value. Thus, the pressure sensor **1** ensures more precise pressure measurement.

Moreover, according to the above-described manufacturing method, the pressure sensor **1** is produced from a single semiconductor substrate **10**. Thus, the pressure sensor **1** realizes a simple manufacturing process and a low manufacturing cost.

Moreover, according to the above-described manufacturing method, the recess **11** having a desired depth can be made easily by adjusting the etching time, so that the dimension in the vertical direction of the cavity portion **13** can be set to a desirable value. Further, according to this manufacturing method, the thickness of the semiconductor layer **30** can be adjusted properly by adjusting the time period for performing CVD, so that the thickness of the semiconductor layer **30** can be set to a desired value.

In this embodiment, the recess **11** is formed by etching the semiconductor substrate **10**. However, unlike this, the recess **11** may be formed by allowing single-crystal silicon to grow on portions of the semiconductor substrate **10** other than the center portion. The sealing of the vent holes **13**A can be performed by a LP-CVD method.

FIGS. **19** and **20** show a pressure sensor according to a second embodiment of the present invention. The pressure sensor **2** of this embodiment is made up of a semiconductor substrate **10**, and an insulating layer **20** and a semiconductor layer **30** formed on the semiconductor substrate. The pressure sensor is provided with a cavity portion **13**, a movable portion **31** and electrodes **51**, **52**.

The semiconductor substrate **10** is e.g. a single-crystal silicon (Si) substrate. The center of the surface of the semiconductor substrate **10** is thermally oxidized to be formed with an insulating layer **22**. The insulating layer **22** has a thickness of e.g. 0.3 to 1 μm.

The semiconductor layer **30** is made of e.g. polycrystalline silicon (Si) and formed on the semiconductor substrate **10**, with the insulating layer **21** or **23**, which will be described later, intervening between them. The semiconductor layer **30** has a thickness of e.g. 2 to 10 μm. The semiconductor layer **30** is formed over the substantially entire surface of the semiconductor substrate **10**, except the right end in FIG. **20**. It is to be noted that the semiconductor layer **30** is not provided at portions corresponding to vent holes **13**A formed in the manufacturing process, which will be described below.

The insulating layer **20** is made of e.g. silicon dioxide (SiO_2). The insulating layer **20** is made up of insulating layers **21**, **22**, **23**, **27**, which are made in different steps in the manufacturing process as will be described later, and has a vacuum cavity portion **13** in it. As noted before, the insulating layer **22** is provided on the surface of the semiconductor substrate **10**.

The insulating layer **21** provides insulation between the semiconductor substrate **10** and the semiconductor layer **30**. The insulating layer **21** is not provided on the semiconductor layer **10** at the portion where the insulating layer **22** is provided. The thickness of the insulating layer **21** is e.g. 1 to 2 μm. The insulating layer **23** is provided on the lower surface of the semiconductor layer **30** to cover the portions of the lower surface which are not in contact with the insulating layer **21**. The thickness of the insulating layer **23** is e.g. 0.3 to 0.5 μm. The cavity portion **13** is in the form of a rectangular parallelepiped and provided inside the insulating layer **21** to be sandwiched between the semiconductor layers **22** and **23** in the vertical direction. The dimension of the cavity portion **13** in the vertical direction is e.g. 1 to 1.7 μm, and that in the horizontal direction is e.g. 300 to 500 μm. The insulating layer **27** covers the semiconductor layer **30** and the right end in FIG. **20** of the semiconductor substrate **10**. The thickness of the insulating layer **27** on the semiconductor layer **30** is e.g. 0.3 to 0.5 μm. The insulating layer **27** includes a plurality of sealing portions **27**a which seal the portions corresponding to vent holes **13**A formed in the manufacturing process, which will be described later. The sealing portions **27**a are formed to be concave relative to the surrounding portions. The sealing portions **27**a can be made flat by CMP. The insulating layer **27** includes a through-hole **27**b penetrating in the lamination direction at the left end in FIG. **27** and a through-hole **27**c penetrating in the lamination direction at the right end in FIG. **27**.

The electrode **51** is formed to be electrically connected to the semiconductor layer **30** via the through-hole **27**b. The electrode **52** is formed to be electrically connected to the semiconductor substrate **10** via the through-hole **27**c.

The movable portion **31** comprises a portion of the semiconductor layer **30** which overlaps the cavity portion **13** in the lamination direction, and portions of the insulating layers **23**, **27** on and under this portion of the semiconductor layer. The movable portion **31** is movable up and down in the lamination direction.

A method for manufacturing the pressure sensor **2** is described below with reference to FIGS. **21-35**.

First, a semiconductor substrate **10** made of single-crystal silicon is prepared. Specifically, a semiconductor substrate **10** having a thickness of 300 to 700 μm is prepared. In the next step, as shown in FIG. **21**, an insulating layer **21** of SiO_2 is formed on the surface of the semiconductor substrate **10**. This step can be performed by thermally oxidizing the upper surface of the semiconductor substrate **10**. In this step, the upper surface of the semiconductor substrate **10** can be heated uniformly so that the thickness of the insulating layer **21** is uniform. Moreover, in this step, the thickness of the insulating layer **21** can be adjusted appropriately by adjusting the heating time.

In the next step, as shown in FIG. **22**, an opening **21**a for exposing the surface of the semiconductor substrate **10** is formed in the insulating layer **21**. This step is performed by providing a resist of resin which exposes the portion where the opening **21**a is to be formed and performing wet etching using aqueous solution of hydrogen fluoride. Alternatively, this step can be performed by gas-phase etching using the reaction between fluorine-containing molecular ions (HF_2^-) and SiO_2. HF_2^- can be obtained by reacting hydrogen fluoride (HF) with water vapor. HF can be obtained by reacting F or molecular fluorine (F_2), which is obtained by e.g. decomposing by discharge carbon tetrafluoride (CF_4) gas or sulfur hexafluoride (SF_6) gas, with water vapor. Since Si which is not oxidized does not easily react with HF_2^-, the semiconductor substrate **10** is not removed by the etching.

In the next step, an insulating layer **22** is formed, as shown in FIG. **23**. This step can be performed by thermally oxidizing the portion of the semiconductor substrate **10** which is exposed through the opening **21**a.

In the next step, as shown in FIG. **24**, a sacrificial layer **12** is formed. The sacrificial layer **12** is a layer of polycrystalline silicon. This step is performed by e.g. embedding polycrystalline silicon in the opening **21**a. The polycrystalline silicon to be embedded in the opening **21**a is processed in advance such that the surface of the sacrificial layer **12** is flush with the surface of the insulating layer **21**.

In the next step, as shown in FIG. **25**, an insulating layer **23** of SiO_2 is formed. This step can be performed by thermally oxidizing the surface of the sacrificial layer **12**. By this step, the sacrificial layer **12** is enclosed by the insulating layers **21**, **22**, **23**.

In the next step, a semiconductor layer **30** is formed, as shown in FIG. **26**. This step can be performed by causing polycrystalline silicon to grow on the surfaces of the insulating layer **21**, **23** by e.g. chemical vapor deposition (CVD).

In the next step, as shown in FIG. **27**, an insulating layer **24** of SiO_2 is formed on the surface of the semiconductor layer **30**. This step can be performed by thermally oxidizing the surface of the semiconductor layer **30**.

In the next step, a plurality of through-holes **24**a are formed in the insulating layer **24**, as shown in FIG. **28**. At the same time, in this step, the right end in the figure of the insulating layer **24** is removed to expose the right end of the semiconductor layer **30**. This step can be performed by gas-phase etching using the reaction between fluorine-containing molecular ions (HF_2^-) and SiO_2. HF_2^- can be obtained by reacting hydrogen fluoride (HF) with water vapor. HF can be obtained by reacting atomic fluorine (F) or molecular fluorine (F_2), which is obtained by e.g. decomposing CF_4 gas or SF_6 gas, with water vapor. Since Si which is not oxidized does not easily react with HF_2^-, the semiconductor layer **30** is not removed by the etching and hence remains.

In the next step, as shown in FIG. **29**, a plurality of through-holes **30**a are formed in the semiconductor layer **30** so that each of the through-holes **30**a is connected to a respective one of the through-holes **24**a at the upper end and reaches the insulating layer **23** at the lower end. This step can be performed by gas-phase etching using gas containing HF. The gas containing HF can be prepared by e.g. decomposing by discharge a gas obtained by adding water vapor to CF_4 gas or SF_6 gas. By performing etching while keeping HF in a dry state and suppressing generation of HF_2^-, SiO_2 is prevented from being etched away. In this step, therefore, the insulating layers **23** and **24** remain. Further, in this step, the right end of the semiconductor layer **30** is removed, so that the insulating layer **21**b, which is the right end portion of the insulating layer **21**, is exposed.

In the next step, insulating layers **25** and **26** of SiO_2 are formed, as shown in FIG. **30**. The insulating layer **25** is formed on the inner circumferential surface of each of the through-holes **30**a. The insulating layer **26** is formed on the semiconductor layer **30** at the portion that is not covered with the insulating layers **21**, **24**. This step is performed by thermally oxidizing the portion of the semiconductor layer **30** which is not covered with the insulating layers **21**, **24**.

In the next step, a resist **40** is applied, as shown in FIG. **31**. The resist **40** is made of e.g. resin and covers the insulating layer **24** and the insulating layer **21**b but does not cover the through-holes **24**a. This step is performed by applying liquefied resin to the surfaces of the insulating layer **24** and the insulating layer **21**b.

In the next step, vent holes **13**A are formed, as shown in FIG. **32**. The vent holes **13**A are made by forming through-holes **23**a in the insulating layer **23** such that each of the through-holes **23**a is connected to one of the through-holes **24**a and one of the through-hole **30**a. This step can be performed by gas-phase etching using the reaction between HF_2^- and SiO_2. In this step, the resist **40** is removed after the vent holes **13**A are formed.

In the next step, a cavity portion **13** is formed, as shown in FIG. **33**. This is performed by removing the sacrificial layer **12**. The removal of the sacrificial layer **12** is performed by gas-phase etching, i.e., sending gas containing F to the sacrificial layer **12** through the vent holes **13**A. F can be obtained by e.g. decomposing CF_4 gas or SF_6 gas. Since F does not easily react with SiO_2, the insulating layers **21**, **22**, **23**, **24**, **25**, **26** remain in this step, and the semiconductor substrate **10** and the semiconductor layer **30** protected by these insulating layers also remain. By forming the cavity portion **13** in this way, the portion of the semiconductor layer **30** which overlaps the cavity portion **13** as viewed in the lamination direction and the insulating layers **23**, **24** on and under this portion become the movable portion **31**.

In the next step, an insulating layer **27** and sealing portions **27***a* are formed, as shown in FIG. **34**. In this step, for instance, plasma CVD is performed in a vacuum atmosphere. In this step, SiO_2 is further deposited on the insulating layers **21***b*, **24**, **25**, **26**. As a result of deposition of SiO_2 on the insulating layer **25**, the vent holes **13**A are sealed to become sealing portions **27***a*. As a result of deposition of SiO_2 on the insulating layers **21***b*, **24**, **26**, the insulating layer **27** is provided.

In the next step, through-holes **27***b* and **27***c* are formed, as shown in FIG. **35**. Specifically, the through-holes **27***b* and **27***c* are formed by providing a resist of resin such that the portions where the through-holes **27***b* and **27***c* are to be formed are exposed and performing wet etching using aqueous solution of hydrogen fluoride or gas-phase etching using the reaction between HF_2^- and SiO_2. The through-hole **27***b* reaches the semiconductor layer **30**, and the through-hole **27***c* reaches the semiconductor substrate **10**.

After the above-described steps, electrodes **51** and **52** are provided, whereby the pressure sensor **2** shown in FIGS. **19** and **20** is completed. For instance, the electrodes **51** and **52** are provided by forming an Al layer in the through-holes **27***b*, **27***c* and on the insulating layer **27** and then removing unnecessary portions of the Al layer by etching.

The operation and advantages of the pressure sensor **2** are described below.

According to this embodiment, when the movable portion **31** moves up and down, the capacitance between the semiconductor substrate **10** and the semiconductor layer **30** changes. The pressure sensor **2** detects such changes in capacitance between the semiconductor substrate **10** and the semiconductor layer **30** to detect changes in pressure applied to the movable portion **31**. Since the cavity portion **13** is in a vacuum state, the pressure sensor **1** is suitable for measuring e.g. the absolute pressure applied to the movable portion **31**.

According to the present invention, the cavity portion **13** is surrounded by the insulating layers **21**, **22** and **23**. Thus, in the pressure sensor **2**, the capacitance between the semiconductor substrate **10** and the semiconductor layer **30** is relatively large. A larger capacitance between the semiconductor substrate **10** and the semiconductor layer **30** allows more sensitive detection of changes in the capacitance. Thus, the pressure sensor **2** ensures more precise pressure measurement.

Further, according to this embodiment, the insulating layer **22** is formed by oxidizing part of the surface of the semiconductor substrate **10**, so that it is easy to make the thickness of the insulating layer uniform. The semiconductor layer **30** is formed on the insulating layers **21** and **23** which are made flush with each other. Thus, in the pressure sensor **2**, the semiconductor substrate **10** and the semiconductor layer **30** are parallel to each other, with the cavity portion **13** intervening between them. This arrangement allows the capacitance between the semiconductor substrate **10** and the semiconductor layer **30** to be set precisely to a predetermined value. Thus, the pressure sensor **2** ensures more precise pressure measurement.

Moreover, according to the above-described manufacturing method, the pressure sensor **2** is produced from a single semiconductor substrate **10**. Thus, the pressure sensor **2** realizes a simple manufacturing process and a low manufacturing cost.

Moreover, according to the above-described manufacturing method, the dimension in the vertical direction of the cavity portion **13** depends on the thickness of the insulating layer **21**, and the thickness of the insulating layer **21** can be adjusted relatively easily by adjusting the time period for performing thermal oxidization. Further, according to this manufacturing method, the thickness of the semiconductor layer **30** can be adjusted properly by adjusting the time period for performing CVD, so that the thickness of the semiconductor layer **30** can be set to a desired value.

Although the sealing of the vent holes **13**A is performed by plasma CVD in the above-described embodiment, the sealing can be performed by e.g. low pressure chemical vapor deposition (LPCVD).

FIGS. **36** and **37** show a pressure sensor according to a third embodiment of the present invention. The pressure sensor **3** of this embodiment is made up of a semiconductor substrate **10**, and an insulating layer **20** and a semiconductor layer **30** laminated on the semiconductor substrate. The pressure sensor is provided with a cavity portion **13**, a movable portion **31** and electrodes **51**, **52**.

The semiconductor substrate **10** is e.g. a single-crystal silicon (Si) substrate and has a recess **11** extending inward in the lamination direction (vertical direction in FIG. **37**) at the center. The depth of the recess **11** is e.g. 5 to 15 μm. The cavity portion **13** and the semiconductor layer **30** are provided in the recess **11**. The cavity portion **13** is in a vacuum state and provided adjacent to the bottom of the recess **11**. The dimension of the cavity portion **13** in the vertical direction is e.g. 2 to 5 μm, and that in the horizontal direction is e.g. 300 to 500 μm. The semiconductor layer **30** is made of e.g. polycrystalline silicon and provided in such a manner as to close the recess **11**. The semiconductor layer **30** has a thickness of e.g. 2 to 10 μm. The surface of the semiconductor layer **30** is made flush with the semiconductor substrate **10** at portions other than the portion where the recess **11** is provided.

The insulating layer **20** is made of e.g. silicon dioxide (SiO_2). The insulating layer **20** is made up of insulating layers **22**, **23**, **27**, which are made in different steps in the manufacturing process, as will be described later.

The insulating layer **22** covers the surface of the recess **11** which faces the cavity portion **13**. The thickness of the insulating layer **22** is e.g. 0.3 to 1.0 μm. The insulating layer **23** covers the surface of the semiconductor layer **30** which faces the cavity portion **13**. The thickness of the insulating layer **23** is e.g. 0.3 to 1.0 μm. The insulating layer **27** covers the surface of the semiconductor substrate **10** and the surface of the semiconductor layer **30**. The thickness of the insulating layer **27** is e.g. 1 to 2 μm. The insulating layer **27** includes a plurality of sealing portions **27***a* which seal the portions corresponding to vent holes **13**A formed in the manufacturing process, which will be described later. The sealing portions **27***a* are formed to be concave relative to the surrounding portions. The sealing portions **27***a* can be made flat by CMP. The insulating layer **27** includes a through-hole **27***b* penetrating in the lamination direction at the center in FIG. **37** and a through-hole **27***c* penetrating in the lamination direction at the right side in FIG. **37**.

The electrode **51** is formed to be electrically connected to the semiconductor layer **30** via the through-hole **27***b*. The electrode **52** is formed to be electrically connected to the semiconductor substrate **10** via the through-hole **27***c*.

The movable portion **31** comprises the semiconductor layer **30** and the insulating layers **23**, **27** on and under the semiconductor layer. The movable portion **31** is movable up and down in the lamination direction.

A method for manufacturing the pressure sensor **3** is described below with reference to FIGS. **38-53**.

First, a semiconductor substrate **10** made of single-crystal silicon is prepared. Specifically, a semiconductor substrate **10** having a thickness of 300 to 700 μm is prepared. In the next step, as shown in FIG. **38**, an insulating layer **21** of SiO_2 is formed on the surface of the semiconductor substrate **10**. This step can be performed by thermally oxidizing the surface of the semiconductor substrate **10**.

In the next step, as shown in FIG. **39**, an opening **21***a* for exposing the surface of the semiconductor substrate **10** is formed in the insulating layer **21**. This step is performed by providing a resist of resin which exposes the portion where the opening **21***a* is to be formed and performing wet etching using aqueous solution of hydrogen fluoride (HF).

In the next step, a recess **11** is formed in the semiconductor substrate **10**, as shown in FIG. **40**. This step can be performed by gas-phase etching using gas containing atomic fluorine (F). Fluorine (F) reacts with silicon (Si) but does not react with SiO_2. Thus, the insulating layer **21** is not etched away, and the semiconductor substrate **10** is etched away at the portion exposed through the opening **21***a*, whereby the recess **11** is formed. In this step, by adjusting the time of dry etching, the recess **11** of a desired depth can be formed. The gas containing F can be obtained by decomposing carbon tetrafluoride (CF_4) gas or sulfur hexafluoride (SF_6) gas by discharge.

In the next step, an insulating layer **22** is formed, as shown in FIG. **41**. This step can be performed by thermally oxidizing the surface of the recess **11**.

In the next step, as shown in FIG. **42**, a sacrificial layer **12**A is formed in the recess **11**. The sacrificial layer **12**A is a layer of polycrystalline silicon. This step is performed by e.g. embedding polycrystalline silicon in the recess **11**. In this step, the entirety of the interior of the recess **11** is filled with polycrystalline silicon. Further, in this step, the surface of the polycrystalline silicon is abraded such that the surface of the sacrificial layer **12** is flush with the surface of the insulating layer **21**.

In the next step, a sacrificial layer **12** is made from the sacrificial layer **12**A, as shown in FIG. **43**. This step is performed by removing the portion close to the surface of the sacrificial layer **12**A by gas-phase etching using gas containing HF. The gas containing HF can be prepared by e.g. decomposing by discharge a gas obtained by adding water vapor to CF_4 gas or SF_6 gas. By performing etching while keeping HF in a dry state and suppressing generation of HF_2^-, SiO_2 is prevented from being etched away. Thus, the insulating layers **21** and **22** are not removed by this etching. In this step, the thickness of the sacrificial layer **12** can be adjusted by adjusting the etching time.

In the next step, as shown in FIG. **44**, an insulating layer **23** of SiO_2 is formed. This step can be performed by thermally oxidizing the surface of the sacrificial layer **12**.

In the next step, as shown in FIG. **45**, the semiconductor layer **30** is formed. This step is performed by e.g. embedding polycrystalline silicon in an upper portion of the recess **11**. The "upper portion of the recess **11**" in this step means a portion of the recess **11** which is above the insulating layer **23**.

In the next step, as shown in FIG. **46**, an insulating layer **24** of SiO_2 is formed. First, in this step, the surface of the semiconductor layer **30** is thermally oxidized. Preferably, the thermal oxidation is performed through the thickness portion which is substantially the same as that of the insulating layer **21**. By heating the surface of the semiconductor layer **30** uniformly, an oxide layer having a uniform thickness is formed. Then, low pressure chemical vapor deposition (LPCVD) using tetraethoxysilane (TEOS) is performed so that SiO_2 is further deposited on the already formed oxide layer and the insulating layer **21**, whereby the insulating layer **24** is formed. The insulating layer **24** is formed such that its thickness is sufficiently larger than the thickness of the insulating layer **23**.

In the next step, as shown in FIG. **47**, a plurality of through-holes **24***a* are formed in the insulating layer **24**. This step can be performed by gas-phase etching using the reaction between fluorine-containing molecular ions (HF_2^-) and SiO_2. HF_2^- can be obtained by reacting hydrogen fluoride (HF) with water vapor. HF can be obtained by reacting F or molecular fluorine (F_2), which is obtained by e.g. decomposing CF_4 gas or SF_6 gas, with water vapor. Since Si which is not oxidized does not easily react with HF_2^-, the semiconductor layer **30** is not removed by the etching and hence remains.

In the next step, as shown in FIG. **48**, a plurality of through-holes **30***a* are formed in the semiconductor layer **30** so that each of the through-holes **30***a* is connected to a respective one of the through-holes **24***a* at the upper end and reaches the insulating layer **23** at the lower end. This step can be performed by gas-phase etching using gas containing HF. The gas containing HF can be prepared by e.g. decomposing by discharge a gas obtained by adding water vapor to CF_4 gas or SF_6 gas. By performing etching while keeping HF in a dry state and suppressing generation of HF_2^-, SiO_2 is prevented from being etched away. In this step, therefore, the insulating layers **23** and **24** remain.

In the next step, an insulating layer **25** of SiO_2 is formed, as shown in FIG. **49**. The insulating layer **25** is formed on the inner circumferential surface of each of the through-holes **30***a*. This step is performed by thermally oxidizing the portion of the semiconductor layer **30** which is not covered with the insulating layer **24**.

In the next step, vent holes **13**A are formed, as shown in FIG. **50**. The vent holes **13**A are made by forming through-holes **23***a* in the insulating layer **23** such that each of the through-holes **23***a* is connected to one of the through-holes **24***a* and one of the through-hole **30***a*. This step can be performed by gas-phase etching using the reaction between HF_2^- and SiO_2. This step can be performed by utilizing the difference in thickness between the insulating layer **23** and the insulating layer **24**, without providing a resist. By this step, part of the insulating layer **24** is removed.

In the next step, a cavity portion **13** is formed, as shown in FIG. **51**. This step can be performed by removing the sacrificial layer **12**. The removal of the sacrificial layer **12** is performed by gas-phase etching, i.e., by sending gas containing F to the sacrificial layer **12** through the vent holes **13**A. F can be obtained by e.g. decomposing CF_4 gas or SF_6 gas. Since F does not easily react with SiO_2, the insulating layers **22**, **23**, **24**, **25** remain in this step, and the semiconductor substrate **10** and the semiconductor layer **30** protected by these insulating layers also remain. By forming the cavity portion **13** in this way, the portion of the semiconductor layer **30** which overlaps the cavity portion **13** as viewed in the lamination direction and the insulating layers **23**, **24** on and under this portion become the movable portion **31**.

In the next step, an insulating layer **27** and sealing portions **27***a* are formed, as shown in FIG. **52**. In this step, for instance, plasma CVD is performed in a vacuum atmosphere. In this step, SiO_2 is further deposited on the insulating layers **24** and **25**. As a result of deposition of SiO_2 on the insulating layer **25**, the vent holes **13**A are sealed to become sealing portions **27***a*. As a result of deposition of SiO_2 on the insulating layer **24**, the insulating layer **27** is provided.

In the next step, through-holes **27***b* and **27***c* are formed, as shown in FIG. **53**. Specifically, the through-holes **27***b* and **27***c* are formed by providing a resist of resin such that the portions where the through-holes **27***b* and **27***c* are to be formed are exposed and performing wet etching using aqueous solution of hydrogen fluoride or gas-phase etching using the reaction between HF_2^- and SiO_2. The through-hole **27***b* reaches the semiconductor layer **30**, and the through-hole **27***c* reaches the semiconductor substrate **10**.

After the above-described steps, electrodes **51** and **52** are provided, whereby the pressure sensor **3** shown in FIGS. **36** and **37** is completed. For instance, the electrodes **51** and **52** are provided by forming an Al layer in the through-holes **27***b*, **27***c* and on the insulating layer **27** and then removing unnecessary portions of the Al layer by etching.

The operation and advantages of the pressure sensor **3** are described below.

According to this embodiment, when the movable portion **31** moves up and down, the capacitance between the semiconductor substrate **10** and the semiconductor layer **30** changes. The pressure sensor **3** detects such changes in capacitance between the semiconductor substrate **10** and the semiconductor layer **30** to detect changes in pressure applied to the movable portion **31**. Since the cavity portion **13** is in a vacuum state, the pressure sensor **3** is suitable for e.g. measuring the absolute pressure applied to the movable portion **31**.

According to the present invention, the cavity portion **13** is surrounded by the insulating layers **22** and **23**. Thus, in the pressure sensor **3**, the capacitance between the semiconductor substrate **10** and the semiconductor layer **30** is relatively large. A larger capacitance between the semiconductor substrate **10** and the semiconductor layer **30** allows more sensitive detection of changes in the capacitance. Thus, the pressure sensor **3** ensures more precise pressure measurement.

Further, according to this embodiment, the recess **11** is formed by etching so that the bottom surface of the recess is parallel to the surface of the semiconductor substrate **10**. Moreover, the sacrificial layer **12** is formed by etching the sacrificial layer **12**A which has been abraded to correspond to the surface of the semiconductor substrate **10**. Thus, the surface of the insulating layer **23**, which is formed by thermally oxidizing the surface of the sacrificial layer **12**, is parallel to the surface of the semiconductor substrate **10**. Accordingly, in the pressure sensor **3**, the bottom surface of the recess **11** and the semiconductor layer **30** are parallel to each other, with the cavity portion **13** intervening between them. This arrangement allows the capacitance between the semiconductor substrate **10** and the semiconductor layer **30** to be set precisely to a predetermined value. Thus, the pressure sensor **3** ensures more precise pressure measurement.

Moreover, according to the above-described manufacturing method, the pressure sensor **3** is produced from a single semiconductor substrate **10**. Thus, the pressure sensor **3** realizes a simple manufacturing process and a low manufacturing cost.

Moreover, according to the above-described manufacturing method, the depth of the recess **11** and the thickness of the sacrificial layer **12** can be easily adjusted by adjusting the etching time in each step. Thus, the dimension in the vertical direction of the cavity portion **13** and the thickness of the semiconductor layer **30** can be set to a desirable value.

In this embodiment, the recess **11** is formed by etching the semiconductor substrate **10**. However, unlike this, the recess **11** may be formed by allowing single-crystal silicon to grow on portions of the semiconductor substrate **10** other than the center portion. The sealing of the vent holes **13**A can be performed by a LPCVD method.

The pressure sensor according to the present invention is not limited to the foregoing embodiments. The specific structure of each part of the pressure sensor according to the present invention can be varied in design in many ways. For instance, although a capacitive pressure sensor is shown in the foregoing embodiments, the present invention is also applicable to a pressure sensor that uses a piezoresistor. Although the cavity portion **13** is in a vacuum state in the foregoing embodiments, the cavity portion may be filled with a gas of a given pressure.

In the foregoing embodiments, the semiconductor substrate **10** is made of single-crystal silicon, whereas the semiconductor layer **30** is made of polycrystalline silicon. Unlike this, however, the semiconductor substrate **10** may be made of polycrystalline silicon, whereas the semiconductor layer **30** may be made of single-crystal silicon. Moreover, the sacrificial layer **12** may be made of single-crystal silicon.

FIGS. **54** and **55** show a pressure sensor according to a fourth embodiment of the present invention. The pressure sensor **101** of this embodiment is made up of a semiconductor substrate **110**, and an oxide film **121** and a semiconductor layer **130** formed on the semiconductor substrate. The pressure sensor is provided with sealing members **141**, a movable portion **161**, and piezoresistors **171**, **172**, **173**, **174**. The pressure sensor **101** is further provided with a bridge circuit in which the piezoresistors **171**, **172**, **173**, **174** are included. The bridge circuit is arranged on the semiconductor layer **130** and includes output terminals Vout+, Vout−, a bias voltage application terminal Vdd, ground terminals **151**, **152**, **153** and leads **154**, **155**, **156**, **157**, **158**. The ground terminals **151**, **152**, **153** are grounded.

The semiconductor substrate **110** is a single-crystal silicon (Si) substrate having a thickness of about 300 μm in the lamination direction (vertical direction in FIG. **55**), and includes a cavity portion **111** the inside of which is in a vacuum state or at a given pressure. The cavity portion **111** is open at the surface of the semiconductor substrate **110** and has a depth of 1 to 50 μm in the lamination direction. The cavity portion **111** is circular as viewed in the thickness direction and has a diameter of e.g. 100 to several thousand micrometers. The shape of the cavity portion **111** as viewed in the lamination direction is not limited to a circular shape, but may be a polygonal shape such as a rectangle.

The semiconductor layer **130** is made of e.g. single-crystal silicon and formed on the semiconductor substrate **110** to have a thickness of about 1 to 50 μm. The semiconductor layer **130** has a plurality of through-holes **130***a* in an area overlapping the cavity portion **111** as viewed in the lamination direction. Each of the through-holes **130***a* penetrates the semiconductor layer **130** in the lamination direction, and an oxide film **131** having a thickness of about 0.2 μm is formed on the inner circumferential surface of the through-hole. As viewed in the lamination direction, the through-hole **130***a* has a circular shape with a diameter of 0.2 to 5 μm or an oval shape having a similar size.

The oxide film **121** is made of e.g. a silicon dioxide (SiO_2) and formed between the semiconductor substrate **110** and the semiconductor layer **130** to have a thickness of about 0.1 to 3 μm. The oxide film **121** has a plurality of through-holes **121***a* that overlap the through-holes **130***a* as viewed in the lamination direction. Each of the through-holes **121***a* penetrates the oxide film **121** in the lamination direction and reaches one of the through-holes **130***a* at the upper end and reaches the cavity portion **111** at the lower end.

The sealing members **141** are made of e.g. silicon dioxide (SiO_2) and seal the upper end of each through-hole **130***a*.

The movable portion **161** comprises portions of the semiconductor layer **130** and the oxide film **121** which overlap the cavity portion **111** as viewed in the lamination direction. Since the movable portion **161** overlaps the cavity portion

111, the movable portion is deformable in the lamination direction. The shape of the movable portion **161** as viewed in the lamination direction is the same as that of the cavity portion **111**.

As shown in FIG. **54**, each of the piezoresistors **171**, **172**, **173**, **174** is in the form of a meandering strip including a plurality of bends, and embedded in the semiconductor layer **130**. The thickness of the piezoresistors **171**, **172**, **173**, **174** in the lamination direction is e.g. about 0.1 to 1 μm. The piezoresistor **171** is arranged at the upper end of the movable portion **161** in FIG. **54**. The piezoresistor **172** is arranged at the left end of the movable portion **161** in FIG. **54**. The piezoresistor **173** is arranged at the lower end of the movable portion **161** in FIG. **54**. The piezoresistor **174** is arranged at the right end of the movable portion **161** in FIG. **54**. The piezoresistors **171** and **173** are located within the area of the movable portion **161**, whereas the piezoresistors **172** and **174** are located at the edge of the movable portion **161**. The piezoresistors **171**, **172**, **173**, **174** are made of doped polysilicon or by doping a P-type or N-type element.

The piezoresistor **171** is connected at one end to the ground terminal **151** via the lead **154** and connected at the other end to the output terminal Vout+.

The piezoresistor **172** is connected at one end to the output terminal Vout+ via the lead **155** and connected at the other end to the bias voltage application terminal Vdd via the lead **156**.

The piezoresistor **173** is connected at one end to the bias voltage application terminal Vdd via the lead **156** and connected at the other end to the output terminal Vout−.

The piezoresistor **174** is connected at one end to the output terminal Vout− via the lead **157** and connected at the other end to the ground terminal **152** via the lead **158**.

The operation and advantages of the pressure sensor **101** are described below.

In the pressure sensor **101**, when pressure is applied to the surface of the movable portion **161**, the movable portion **161** is deformed, so that distortion occurs in the piezoresistors **171**, **172**, **173**, **174**. The resistance of the piezoresistors **171**, **172**, **173**, **174** changes due to the distortion. Such a change in resistance of the piezoresistors **171**, **172**, **173**, **174** is detected through the output terminals Vout+, Vout− as a change in voltage relative to the bias voltage applied to the bias voltage application terminal Vdd by using the bridge circuit. Based on the detection result, the pressure applied to the movable portion **161** is calculated. When the cavity portion **111** is in a vacuum state, the pressure applied to the movable portion **161** is the absolute pressure of the ambient gas. When the cavity portion **111** is at a given pressure, the pressure applied to the movable portion **161** is the relative pressure between the ambient gas and the gas within the cavity portion **111**.

A method for manufacturing the pressure sensor **101** is described below with reference to FIGS. **56-69**.

First, as shown in FIG. **56**, a semiconductor substrate **110** having a semiconductor layer **130** on the surface is prepared. The semiconductor layer **130** has an oxide layer **122** on the surface.

In the next step, as shown in FIGS. **57** and **58**, a plurality of through-holes **122***a* are formed in the oxide layer **22**. The shape of the through-holes **122***a* as viewed in the lamination direction is the same as that of the above-described through-holes **130***a*. In this step, for instance, after a resist of resin that exposes the portions where the through-holes **122***a* are to be formed is provided, gas-phase etching using the reaction between fluorine-containing molecular ions (HF_2^-) and SiO_2 is performed. HF_2^- can be obtained by reacting hydrogen fluoride (HF) with water vapor. HF can be obtained by reacting F or molecular fluorine (F_2), which is obtained by e.g. decomposing trifluoromethane (CHF_3) gas, with water vapor. Since Si which is not oxidized does not easily react with HF_2^-, the semiconductor layer **130** is not removed by the etching and hence remains. Instead of the gas-phase etching, wet etching using aqueous solution of hydrogen fluoride (HF) may be performed.

In the next step, as shown in FIG. **59**, a plurality of through-holes **130***a* are formed in the semiconductor layer **130**. This step can be performed by gas-phase anisotropic etching using gas containing HF. The gas containing HF can be prepared by e.g. decomposing by discharge a gas obtained by adding water vapor to CHF_3. By performing etching while keeping HF in a dry state and suppressing generation of HF_2^-, SiO_2 is prevented from being etched away. In this step, therefore, the oxide film **121** and the oxide layer **122** remain.

In the next step, as shown in FIG. **60**, the inner circumferential surface of each through-hole **130***a* is oxidized to form an oxide film **131**. This step can be performed by e.g. thermal oxidization. The oxide film **131** is provided to protect the semiconductor layer **130** during the etching, which will be performed in a later step. The same protection effect is provided by depositing SiO_2 on the inner circumferential surface of the through-holes **130***a* by CVD to form a protective film.

In the next step, vent holes **111**A are formed, as shown in FIGS. **61** and **62**. Each vent hole **111**A is made up of through-holes **121***a*, **122***a*, **130***a*. This step can be performed by gas-phase anisotropic etching using the reaction between HF_2^- and SiO_2. In this gas-phase anisotropic etching, SiO_2 is removed by an amount corresponding to the thickness of the oxide film **121** in the lamination direction. In this step, through-holes **121***a* are formed in the oxide film **121**, while at the same time, the surface portion of the oxide layer **122** is removed.

In the next step, as shown in FIG. **63**, a cavity portion **111** is formed. For instance, this step can be performed by gas-phase etching using gas containing atomic fluorine (F). Fluorine (F) easily reacts with silicon (Si) but does not easily react with SiO_2. Thus, by sending gas containing F to the semiconductor substrate **110** through the vent holes **111**A covered with SiO_2, the semiconductor substrate **110** is etched and the cavity portion **111** is formed before the semiconductor layer **130** is etched. The gas containing F can be obtained by decomposing CHF_3 gas by discharge.

The cavity portion **111** can be formed by etching using xenon fluoride gas. The difference between Si and SiO_2 in reactivity with xenon fluoride gas is larger than that in reactivity with CHF_3 gas. Thus, the oxide film **131** can be made thinner by using xenon fluoride gas.

In the next step, as shown in FIG. **64**, vent holes **111**A are sealed. This step is performed by low pressure chemical vapor deposition (LPCVD) using tetraethoxysilane (TEOS). By this step, SiO_2 is deposited on the oxide layer **122** and in the vent holes **111**A, so that the oxide layer **123** and sealing portions **140** are formed. By sealing the vent holes **111**A with the sealing portions **140** in a vacuum state or in an atmosphere of a given pressure, the cavity portion **111** is brought into a vacuum state or at a given pressure. Of each sealing portion **140**, the portion that closes the vent hole **111**A tends to be concave at the center, because SiO_2 grows radially from the inner circumferential surface of the vent hole **111**A.

The sealing of the vent hole **111**A can be performed by other methods, such as thermal oxidation to utilize bulging of the oxidized portion.

In the next step, as shown in FIG. **65**, the oxide layer **123** is removed. This step can be performed by abrading or gas-phase etching. In this step, at the same time, part of the sealing portions **140** are removed, so that sealing members **141** remain on the upper ends of the through-holes **130***a*. As shown in FIG. **65**, the sealing members **141** are flat at the upper ends and concave toward the center at the lower end. By this step, the movable portion **161** is provided.

In the next step, piezoresistors **171**, **172**, **173**, **174** are formed. Specifically, for instance, the piezoresistors **171**, **172**, **173**, **174** are formed by embedding polycrystalline silicon in the semiconductor layer **130**. Firstly, in this step, grooves **132**, **133**, **134**, **135** are formed, as shown in FIGS. **66** and **67**. Specifically, gas-phase etching using gas containing HF is performed using a resist of resin which exposes portions corresponding to the grooves **132**, **133**, **134**, **135**. Each of the grooves **132**, **133**, **134**, **135** is formed to have a meandering shape including a plurality of bends.

In the next step, as shown in FIGS. **68** and **69**, polycrystalline silicon is embedded in the grooves **132**, **133**, **134**, **135**. The polycrystalline silicon embedded in the grooves **132**, **133**, **134**, **135** in this step becomes the piezoresistors **171**, **172**, **173**, **174**. Alternatively, the piezoresistors **171**, **172**, **173**, **174** can be provided by forming diffused resistors by performing implantation with respect to the semiconductor layer **130**.

Thereafter, e.g. an aluminum (Al) layer is formed on the semiconductor layer **130**. Then, etching is performed with respect to the Al layer, whereby output terminals Vout+, Vout−, a bias voltage application terminal Vdd, ground terminals **151**, **152**, **153** and leads **154**, **155**, **156**, **157**, **158** are formed.

By the above-described steps, the pressure sensor **101** shown in FIGS. **54** and **55** is completed.

The operation and advantages of the pressure sensor **101** are described below.

According to the above-described manufacturing method, the cavity portion **111** and the movable portion **161** are formed by making vent holes **111**A in the semiconductor layer **130** and etching the semiconductor substrate **110** through the vent holes **111**A. Thus, unlike the conventional method which uses a plurality of semiconductor substrates, the pressure sensor **101** is produced from a single semiconductor substrate **110**. Thus, the pressure sensor **101** realizes a simple manufacturing process and a low manufacturing cost.

Moreover, according to the present embodiment, the piezoresistors **171**, **172**, **173**, **174** have a meandering shape including a plurality of bends, which allows distortion due to deformation of the movable portion **161** to occur easily. As a result, the piezoresistors **171**, **172**, **173**, **174** show remarkable changes in resistance when the movable portion **161** is deformed. Thus, the pressure sensor **101** ensures more precise pressure measurement.

FIGS. **70-85** show other embodiments of the present invention. In these figures, the elements which are identical or similar to those of the foregoing embodiments are designated by the same reference signs as those used for the foregoing embodiments.

FIGS. **70** and **71** show a pressure sensor according to a fifth embodiment of the present invention. The pressure sensor **102** shown in FIGS. **70** and **71** differs from the pressure sensor **101** in that the semiconductor layer **130** is made of polycrystalline silicon and in structure of the grooves **132**, **133**, **134**, **135** and piezoresistors **171**, **172**, **173**, **174**. As shown in FIG. **71**, an insulator **136** is filled between the grooves **132**, **133**, **134**, **135** and the piezoresistors **171**, **172**, **173**, **174**. The structures of other parts of the pressure sensor **102** are the same as those of the pressure sensor **101**.

FIGS. **72** and **73** show the step of forming grooves **132**, **133**, **134**, **135** in manufacturing the pressure sensor **102**. As shown in FIGS. **72** and **73**, each of the grooves **132**, **133**, **134**, **135** is formed such that part of the semiconductor layer **130** remains within the groove. The portion of the semiconductor layer **130** which remains in each of the grooves **132**, **133**, **134**, **135** is separated from the main portion of the semiconductor layer **130** by the groove **132**, **133**, **134**, **135**. As shown in FIG. **72**, each groove is formed such that the remaining portion has a meandering shape including a plurality of bends. Such grooves **132**, **133**, **134**, **135** can be formed by performing gas-phase etching using gas containing HF and an appropriate resist of resin. In the pressure sensor **102**, the portion of the semiconductor layer **130** which remains within each of the grooves **132**, **133**, **134**, **135** becomes the piezoresistor **171**, **172**, **173**, **174**.

In the process of manufacturing the pressure sensor **102**, after the step shown in FIGS. **72** and **73**, the step of embedding an insulator **136** in the grooves **132**, **133**, **134**, **135** is performed. In this step, the piezoresistors **171**, **172**, **173**, **174** may be covered with the insulator **136**. Thus, an Al layer is formed after etching is performed with respect to the insulator **136** to expose the piezoresistors **171**, **172**, **173**, **174**. This ensures electrical connection between the piezoresistors **171**, **172**, **173**, **174** and the output terminals Vout+, Vout− and leads **154**, **155**, **156**, **157**, **158**, which are made of the Al layer. In etching the insulator **136**, the portion of the insulator **136** which covers the piezoresistors **171**, **172**, **173**, **174** does not need to be removed entirely. It is sufficient if only portions for allowing connection to the output terminals Vout+, Vout− and leads **154**, **155**, **156**, **157**, **158** are secured in the piezoresistors **171**, **172**, **173**, **174**.

Similarly to the pressure sensor **101**, the pressure sensor **102** is produced from a single semiconductor substrate **110**, without the need for using a plurality of semiconductor substrates. Thus, the pressure sensor **102** realizes a simple manufacturing process and a low manufacturing cost.

Moreover, according to this embodiment again, the piezoresistors **171**, **172**, **173**, **174** have a meandering shape including a plurality of bends, which allows distortion due to deformation of the movable portion **161** to occur easily. As a result, the piezoresistors **171**, **172**, **173**, **174** of this embodiment also show remarkable changes in resistance when the movable portion **161** is deformed. Thus, the pressure sensor **102** ensures more precise pressure measurement.

FIG. **74** shows a pressure sensor according to a sixth embodiment of the present invention. In the pressure sensor **103** of this embodiment, the cavity portion **111** is open to the reverse surface of the semiconductor substrate **110**, and to the opening **111***a* is connected a pipe **163**. The pipe **163** is connected to a gas supply chamber **162**. The structures of the other parts of the pressure sensor **103** are the same as those of the pressure sensor **101**.

For instance, the opening **111***a* can be formed by performing etching from the reverse surface of the semiconductor substrate **110** after the cavity portion **111** is formed.

In the pressure sensor **103**, the gas supply chamber **162** is filled with a gas of a given pressure, and the gas is supplied to the cavity portion **111** through the pipe **163**. With this arrangement, the pressure applied to the reverse surface of the movable portion **161** is known. In this case, the pressure applied to the movable portion **161** is the relative pressure between the pressure of the outside gas applied to the obverse surface side of the movable portion **161** and the known pressure applied to the reverse surface side. Thus, with the pressure sensor **103**, the pressure of the outside gas can be found by detecting the relative pressure of the outside gas with respect to the gas within the cavity portion **111**.

Alternatively, the pressure sensor may be designed such that gas of a given pressure is applied to the obverse surface of the movable portion **161**, while the gas supply chamber **162** is filled with a gas of an unknown pressure. In this case, the pressure of the gas in the gas supply chamber can be measured by supplying the gas to the cavity portion **111** through the pipe **163**.

FIGS. **75** and **76** show a pressure sensor according to a seventh embodiment of the present invention. The pressure sensor **104** shown in FIGS. **75** and **76** includes a pair of plate-like members **112** and **113** projecting from the semiconductor substrate **110** in the lamination direction and facing each other. The height of the plate-like members **112** and **113** in the lamination direction is e.g. in the range of from several micrometers to several tens of micrometers. In the pressure sensor **104**, the movable portion **161** and the cavity portion **111** are in the form of an elongated rectangle as viewed in the lamination direction. The movable portion **161** and the cavity portion **111** are sandwiched between the paired plate-like members **112** and **113**. In this embodiment, piezoresistors **175**, **176**, **177**, **178** each in the form of a thin film are used instead of the piezoresistors **171**, **172**, **173**, **174** of the pressure sensors **101**-**103**. Though not shown in FIGS. **75** and **76**, a bridge circuit including the piezoresistors **175**, **176**, **177**, **178** are formed on the semiconductor layer **130**. The structures of other parts of the pressure sensor **104** are the same as those of the pressure sensor **101**.

FIGS. **77**-**85** show some of the steps of the process of manufacturing the pressure sensor **104**.

FIGS. **77** and **78** show the step of making a pair of plate-like members **112** and **113**. This step comprises preparing a semiconductor substrate **110** in the form of a flat plate, forming oxide layers **112***a* and **113***a* having a thickness of 0.5 μm on the surface of the semiconductor substrate **110**, and etching Si. The oxide layers **112***a* and **113***a* are formed to cover the portions where the plate-like members **112** and **113** are to be formed, as viewed in the lamination direction. For instance, the oxide layers **112***a* and **113***a* are formed by thermally oxidizing the surface of the prepared semiconductor substrate **110** and then etching away unnecessary portions. In the step of Etching Si, gas-phase etching is performed using gas containing F obtained by decomposing CHF_3 gas by discharge. In this etching, the portions covered with the oxide layers **112***a* and **113***a* in the lamination direction remain, so that the shape as shown in FIG. **78** is obtained.

In the next step, an oxide film **121** is formed, as shown in FIG. **79**. This step can be performed by thermally oxidizing the surface of the semiconductor substrate **110**.

In the next step, a semiconductor layer **130** is formed, as shown in FIG. **80**. Specifically, the semiconductor layer **130** is formed by causing polycrystalline silicon to grow by e.g. chemical vapor deposition (CVD). Further, in this step, CMP (chemical mechanical polishing) is performed so that the surface of the semiconductor layer **130** is flush with the surface of the oxide layers **112***a* and **113***a*.

In the next step, as shown in FIG. **81**, the surface of the semiconductor layer **130** is thermally oxidized to form an oxide layer **122**.

In the next step, as shown in FIGS. **82** and **83**, through-holes **122***a* are formed in the oxide layer **122**. Then, as described above by referring to FIGS. **59**-**63** with respect to the fourth embodiment, the step of forming through-holes **130***a*, the step of oxidizing the inner circumferential surfaces of the through-holes **130***a*, the step of forming vent holes **111**A and the step of forming cavity portion **111** are performed, whereby the state shown in FIGS. **84** and **85** is obtained. Thereafter, the step of sealing the vent holes **111**A, the step of removing the oxide layer **122** on the semiconductor layer **130** and the oxide layers **112***a*, **113***a*, the step of forming piezoresistors **175**, **176**, **177**, **178** and the step of forming a bridge circuit are performed, whereby the pressure sensor **104** shown in FIGS. **75** and **76** is completed.

The step of forming piezoresistors **175**, **176**, **177**, **178** can be performed by e.g. doping the material for the piezoresistors **175**, **176**, **177**, **178** in the surface the semiconductor layer **130** and diffusing the material.

In the pressure sensor **104**, similarly to the pressure sensor **101**, the cavity portion **111** and the movable portion **161** are formed by making vent holes **111**A in the semiconductor layer **130** and etching the semiconductor substrate **110** through the vent holes **111**A. Thus, unlike the conventional method which uses a plurality of semiconductor substrates, the pressure sensor **104** is produced from a single semiconductor substrate **110**. Thus, the pressure sensor **104** realizes a simple manufacturing process and a low manufacturing cost.

The pressure sensor according to the present invention is not limited to the foregoing embodiments. The specific structure of each part of the pressure sensor according to the present invention can be varied in design in many ways. For instance, although the pressure sensor **103** has a structure based on the pressure sensor **101**, it may have a structure based on the pressure sensor **102**. The sealing members **141** may fill the entirety of the through-holes **130***a* and may further extend into the through-holes **121***a*.

The pressure sensor **104** may be provided with an opening **111***a*, a pipe **163** and a gas supply chamber **162**, similarly to the pressure sensor **103**. The piezoresistors **175**, **176**, **177**, **178** shown for the pressure sensor **104** may be provided in the pressure sensors **101** and **102**, instead of the piezoresistors **171**, **172**, **173**, **174**. Conversely, the piezoresistors **171**, **172**, **173**, **174** shown for the pressure sensor **102** may be used for the pressure sensor **104**, instead of the piezoresistors **175**, **176**, **177**, **178**.

For instance, although the semiconductor substrate **110** is made of single-crystal silicon Si in the foregoing embodiments, polycrystalline silicon may be used instead.

FIGS. **86** and **87** show a pressure sensor according to an eighth embodiment of the present invention. The pressure sensor **201** of this embodiment includes a semiconductor substrate **221**, a (first) insulating layer **221**, an insulating cover **222**, a (third) insulating cover **223**, an intermediate layer **230** and an electrode layer **240**.

The semiconductor substrate **210** is e.g. a single-crystal silicon (Si) substrate having a thickness of about 300 μm in the lamination direction (vertical direction in FIG. **87**) and includes a cavity portion **211** the inside of which is in a vacuum state or at a given pressure. The cavity portion **211** is open to the obverse surface of the semiconductor substrate **210** and its depth in the lamination direction is e.g. 5 to 100 μm. As viewed in the lamination direction, the cavity portion **211** is in the form of a square, an elongated rectangle, a circle or an oval and has a length of e.g. 50 μm to several millimeters in the horizontal direction in FIG. **86**.

The intermediate layer **230** is formed on the semiconductor substrate **210** and has a thickness of about 1 to 50 μm. The intermediate layer comprises a semiconductor layer **230**A, a recess **231**, a (second) insulating layer **232**, a plurality of through-holes **223** formed in the semiconductor layer **230**A, a protective film **234**, a sealing member **235** and a cavity portion **237**. The semiconductor layer **230**A, which is made of polycrystalline silicon, constitutes most part of the intermediate layer **230**. The remaining part of the intermediate layer is formed by processing the semiconductor layer **230**A, as described later in explaining the manufacturing method.

The recess **231** is provided at a position overlapping the cavity portion **211** as viewed in the lamination direction. The recess **231** extends e.g. about 2 μm inward from the surface of the intermediate layer **230** in the lamination direction. The cavity portion **237** is defined in the recess **231**.

The insulating layer **232** covers the surface of the recess **231**. The thickness of the insulating layer **232** is e.g. about 1.0 μm. For instance, the insulating layer **232** is made of e.g. silicon dioxide (SiO_2).

The through-holes **233** are formed in an area overlapping the recess **231** as viewed in the lamination direction and extend from the surface of the intermediate layer **230** toward the recess **231** in the lamination direction. As viewed in the lamination direction, each of the through-holes **233** has a circular shape with a diameter of 0.5 to 5.0 μm or an oval shape having a similar size.

The protective film **234** is a SiO_2 film having a thickness of about 0.2 μm formed on the inner circumferential surface of each of the through-holes **233**.

The sealing member **235** is made of e.g. SiO_2 and seals the upper end of each of the through-holes **233** in the lamination direction. The sealing member **235** is integral with the insulating layer **232** and the protective film **234**.

The insulating layer **221** is provided between the semiconductor substrate **210** and the intermediate layer **230** and made of e.g. SiO_2. The thickness of the insulating layer **221** is e.g. 0.1 to 1.0 μm. The insulating layer **221** has through-holes **221***a* connected to the through-holes **233**.

The insulating cover **222** covers the surface of the intermediate layer **230** except the surface of the recess **231**, and is made of e.g. SiO_2. The thickness of the insulating cover **222** is e.g. 0.1 to 1 μm. The insulating cover **222** has an opening **222***b* exposing the semiconductor layer **230**A. For instance, the opening **222***b* is provided at the right end in FIG. **86**.

The insulating cover **223** is made of e.g. SiO_2 and provided to close the cavity portion **237**. The thickness of the insulating cover **223** is e.g. 0.1 to 1.0 μm. The shape of the insulating cover **223** as viewed in the lamination direction is the same as that of the bottom surface of the recess **231** and the edges of the insulating cover is integral with the insulating cover **222** and the insulating layer **232**. The insulating cover **223** has a plurality of through-holes **223***a* reaching the hollow portion **237** at the lower ends in the lamination direction.

The electrode layer **240** is formed on the insulating cover **222** or the insulating cover **223** and includes a fixed electrode terminal **241**, a fixed electrode **242**, a movable electrode terminal **243**, a connection line **244** and a filling portion **245**. The electrode layer **240** is made of e.g. aluminum (Al).

The fixed electrode terminal **241** is provided at an appropriate portion on the insulating cover **222** and used for electrical connection to the outside, for example. The fixed electrode **242** is formed on the insulating cover **223** and electrically connected to the fixed electrode terminal **241**. The fixed electrode **242** has a plurality of through-holes **242***a* respectively connected to the through-holes **223***a* at the lower ends in the lamination direction. The fixed electrode **242** covers the entirety of the insulating cover **223**.

The movable electrode terminal **243** is electrically insulated from the fixed electrode terminal **241** and the fixed electrode **242** and provided on the insulating cover **222** to be electrically connected to the filling portion **245** via the connection line **244**. The filling portion **245** fills the opening **222***b* and is in contact with the semiconductor layer **230**A. Thus, the movable electrode terminal **243** is electrically connected to the semiconductor layer **230**A via the connection line **244** and the filling portion **245**.

The operation and advantages of the pressure sensor **201** are described below.

In the pressure sensor **201**, the portion sandwiched between the cavity portions **211** and **237** in the lamination direction serves as a deformable movable portion **261**. With the above-described arrangement, since the insulating cover **223** and the fixed electrode **242** have the through-holes **223***a*, **242***a*, the cavity portion **237** is filled with gas flowing from the outside. On the other hand, as noted before, the cavity portion **211** is in a vacuum state or at a given pressure. Thus, the movable portion **261** is pressed by the gas flowing into the cavity portion **237** and is hence deformed. Since part of the semiconductor layer **230**A is included in the movable portion **261**, when the movable portion **261** is deformed, the capacitance between the fixed electrode **242** and the semiconductor layer **230**A changes. As noted before, the semiconductor layer **230**A is electrically connected to the movable electrode terminal **243**, and the fixed electrode **242** is electrically connected to the fixed electrode terminal **241**. Thus, in the pressure sensor **201**, the semiconductor layer **230**A in the movable portion **261** functions as a movable electrode, and changes in capacitance between the movable portion **261** and the fixed electrode **242** is outputted through the fixed electrode terminal **241** and the movable electrode terminal **243**, whereby the absolute pressure of the gas flowing into the cavity portion **237** is measured.

A method for manufacturing the pressure sensor **201** is described with reference to FIGS. **88** to **106**.

First, the state shown in FIG. **88** is obtained by performing the step of preparing a semiconductor substrate **210** in the form of a flat plate, the step of forming an insulating layer **221** on the surface of the semiconductor substrate **210**, the step of forming a semiconductor layer **230**A on the insulating layer **221** and the step of forming an insulating cover **222** on the semiconductor layer **230**A. The step of forming the insulating layer **221** is performed by e.g. thermally oxidizing the surface of the semiconductor substrate **210**. The step of forming the semiconductor layer **230**A is performed by causing polycrystalline silicon to grow by e.g. chemical vapor deposition (CVD). The step of forming the insulating cover **222** is performed by thermally oxidizing the surface of the semiconductor layer **230**A.

In the next step, as shown in FIGS. **89** and **90**, an opening **222***a* is formed in the insulating cover **222**. The opening **222***a* is formed to expose the portion of the semiconductor layer **230**A where the recess **231** is to be formed. This step is performed by providing a resist of resin which exposes the portion where the opening **222***a* is to be formed and performing gas-phase etching using the reaction between fluorine-containing molecular ions (HF_2^-) and SiO_2. HF_2^- can be obtained by reacting hydrogen fluoride (HF) with water vapor. For instance, HF can be obtained by reacting atomic fluorine (F) and molecular fluorine (F_2), which is obtained by decomposing e.g. CHF_3 gas, with water vapor. Since Si which is not oxidized does not easily react with HF_2^-, the semiconductor layer **230**A is not removed by the etching and hence remains. Instead of the gas-phase etching, wet etching using aqueous solution of hydrogen fluoride (HF) may be performed.

In the next step, a recess **231** is formed, as shown in FIG. **91**. This step can be performed by gas-phase anisotropic etching using gas containing HF. The gas containing HF can be prepared by e.g. decomposing by discharge a gas obtained by adding water vapor to CHF_3 gas. By performing etching while keeping HF in a dry state and suppressing generation of HF_2^-, SiO_2 is prevented from being etched away. In this step, therefore, the insulating cover **222** remains.

In the next step, as shown in FIG. **92**, an insulating layer **232** is formed. This step is performed by thermal oxidization or by causing SiO_2 to grow by CVD. In this step, whichever method is used, the insulating cover **222** becomes thicker at the same time as the insulating layer **232** is formed.

In the next step, a plurality of through-holes **232***a* are formed, as shown in FIGS. **93** and **94**. Each of the through-holes **232***a* is formed to penetrate the insulating layer **232** in the lamination direction to expose the surface of the semiconductor layer **230**A. This step is performed by gas-phase anisotropic etching using the reaction between HF_2^- and SiO_2, similarly to the step of forming the opening **222***a*. In this case, a resist of resin having a plurality of openings corresponding to the through-holes **232***a* is used.

In the next step, a plurality of through-holes **233** are formed, as shown in FIG. **95**. This step can be performed by gas-phase anisotropic etching using gas containing HF, similarly to the step of forming the recess **231**.

In the next step, a protective film **234** is formed, as shown in FIG. **96**. This step is performed by thermal oxidization or by causing SiO_2 to grow by CVD.

In the next step, a vent hole **211**A is formed, as shown in FIG. **97**. The vent hole **211**A is used to introduce etching gas from the outside to the semiconductor substrate **210** and comprises through-holes **221***a*, **232***a* and **233**. Since the through-holes **232***a* and **233** are formed in the previous steps, a plurality of through-holes **221***a* are formed in this step. This step is performed by gas-phase etching using the reaction between HF_2^- and SiO_2. In this step, the insulating cover **222** and part of the insulating layer **232** are also etched to become thinner. When the insulating cover **222** or the insulating layer **232** does not have a sufficient thickness, a resist having the same shape as that used for forming the through-holes **232***a* can be used.

In the next step, a cavity portion **211** is formed, as shown in FIG. **98**. This step is performed by gas-phase etching using gas containing atomic fluorine (F). Fluorine (F) easily reacts with silicon (Si) but does not easily react with SiO_2. Thus, by sending gas containing F to the semiconductor substrate **210** through the vent holes **211**A covered with SiO_2, the semiconductor substrate **210** is etched and the cavity portion **211** is formed before the semiconductor layer **230**A is etched. The gas containing F can be obtained by decomposing CHF_3 gas by discharge.

The step of forming the cavity portion **211** can be performed by etching using xenon fluoride gas. The difference between Si and SiO_2 in reactivity with xenon fluoride gas is larger than that in reactivity with CHF_3 gas. Thus, the protective film **234** can be made thinner by using xenon fluoride gas.

In the next step, the vent hole **211**A is sealed, as shown in FIG. **99**. By this step, part of the insulating layer **232** becomes thicker, while the sealing member **235** is formed. Specifically, in this step, low pressure chemical vapor deposition (LPCVD) using tetraethoxysilane is performed, whereby SiO_2 is deposited on the insulating layer **232** and in the vent holes **211**A. By sealing the vent hole **211**A in a vacuum state or in an atmosphere of a given pressure, the cavity portion **111** is brought into a vacuum state or at a given pressure.

The sealing of the vent hole **211**A can be performed by other methods, such as thermal oxidation to utilize bulging of the oxidized portion or by plasma CVD.

In the next step, a sacrificial layer **236** is formed, as shown in FIG. **100**. This step is performed by e.g. embedding polycrystalline silicon in the recess **231** and the opening **222***a*. In this step, abrading is performed in advance such that the surface of the sacrificial layer **236** is flush with the surface of the insulating cover **222**.

In the next step, an insulating cover **223** is formed, as shown in FIG. **101**. This step can be performed by thermally oxidizing the surface of the sacrificial layer **236**. The thermal oxidization is performed such that the thickness of the insulating cover **223** becomes substantially equal to that of the insulating cover **222**. In the state after this step, the opening **222***a* is filled with the insulating cover **223**, while the recess **231** is filled with the sacrificial layer **236**.

In the next step, through-holes **223***a* and an opening **222***b* are formed, as shown in FIGS. **102** and **103**. This step is performed by providing a resist of resin having openings corresponding to the through-holes **223***a* and the opening **222***b* and performing gas-phase etching using the reaction between HF_2^- and SiO_2.

In the next step, a metal layer **240**A is formed, as shown in FIG. **104**. The metal layer **240**A is a layer made of Al and formed to cover the insulating cover **222** and the insulating cover **223**. In the through-holes **223***a*, the metal layer **240**A is formed directly on the sacrificial layer **236**. In the opening **222***b*, the metal layer is formed directly on the semiconductor layer **230**A. For instance, this step can be performed by depositing Al by CVD.

In the next step, as shown in FIGS. **105** and **106**, the metal layer **240**A is processed to provide an electrode layer **240**. For instance, this step is performed by arranging a resist having the same shape as that of the electrode layer **240** as viewed in the lamination direction and performing gas-phase etching to remove unnecessary portions. The fixed electrode **242** has through-holes **242***a* overlapping the through-holes **223***a* as noted before, so that after this step etching of the sacrificial layer **236** by using the through-holes **223***a* and the through-holes **242***a* as vent holes is possible. Thus, after this step, the sacrificial layer **236** is removed to form the cavity portion **237**. The removal of the sacrificial layer **236** is performed by gas-phase etching using gas containing HF. The intermediate layer **230** is completed by the formation of the cavity portion **237**, whereby the pressure sensor **201** shown in FIGS. **86** and **87** is completed.

The operation and advantages of the pressure sensor **201** are described below.

According to the manufacturing method described above, the cavity portion **211** is formed by etching the semiconductor substrate **210** through the vent hole **211**A, and the cavity portion **237** is formed by etching the sacrificial layer **236** embedded in the recess **231**. Thus, unlike the conventional method which uses a plurality of semiconductor substrates, the pressure sensor **201** is produced from a single semiconductor substrate **210**. Thus, the pressure sensor **1** realizes a simple manufacturing process and a low manufacturing cost.

According to this embodiment, the recess **231** is formed by gas-phase etching so that the bottom surface naturally becomes parallel to the surface of the insulating cover **222**. Meanwhile, the fixed electrode **242** is formed on the insulating cover **223**, which is formed to be flush with the surface of the insulating cover **222**. Thus, the reverse surface of the fixed electrode **242** and the bottom surface of the recess **231** which corresponds to the surface of the movable electrode of the pressure sensor **201** naturally become parallel to each other. Moreover, the depth of the recess **231** is easily adjusted by adjusting the etching time. This allows the capacitance between the fixed electrode **242** and the movable portion **261** to be set precisely to a predetermined value. Thus, the pressure sensor **201** ensures more precise pressure measurement.

Moreover, according to the present invention, the recess **231** is covered with the insulating layer **232**, and the reverse surface of the fixed electrode **242** is covered with the insulating cover **223**. Thus, the capacitance between the fixed electrode **242** and the movable portion **261** is relatively large. A larger capacitance between the fixed electrode **242** and the movable portion **261** allows more sensitive detection of changes in the capacitance. Thus, the pressure sensor **201** ensures more precise pressure measurement.

FIGS. **107-124** show other embodiments of the present invention. In these figures, the elements which are identical or similar to those of the foregoing embodiments are designated by the same reference signs as those used for the foregoing embodiments.

FIG. **107** shows a pressure sensor according to a ninth embodiment of the present invention. The pressure sensor **202** of this embodiment has the same structure as that of the pressure sensor **201** except that it does not have the insulating cover **223** provided in the pressure sensor **201**. Since the insulating cover **223** is not provided, the fixed electrode **242** of the pressure sensor **202** is made larger than the recess **231** as viewed in the lamination direction and supported on the insulating cover **222**. The pressure sensor **202** is manufactured by omitting the steps of forming the insulating cover **223** and forming through-holes **223***a* from the method for manufacturing the pressure sensor **201**. Thus, the pressure sensor **202** realizes a more simple manufacturing process.

FIG. **108** shows a pressure sensor according to a tenth embodiment of the present invention. In the pressure sensor **203** of this embodiment, the cavity portion **211** is open to the reverse surface of the semiconductor substrate **210**, and to the opening **211***a* is connected a pipe **263**. The pipe **263** is connected to a gas supply chamber **262**. The structures of the other parts of the pressure sensor **203** are the same as those of the pressure sensor **201**.

To form the opening **211***a*, before the semiconductor layer **230**A is formed on the semiconductor substrate **210**, etching is performed with respect to the reverse surface of the semiconductor substrate **210** and a recess for connection to the cavity portion **211**, which is formed later, is formed.

The gas supply chamber **262** is used to supply gas of a given pressure to the cavity portion **211**. Thus, unlike the pressure sensor **201**, the inside of the cavity portion **211** of the pressure sensor **203** is filled with a gas of the given pressure. The movable portion **261** receives pressure from each of the gas in the cavity portion **211** and the gas in the cavity portion **237** and is deformed in accordance with the relative pressure. Thus, the pressure sensor **230** can measure the relative pressure between the pressure of the outside gas and the pressure of the gas in the cavity portion **211** which is supplied from the gas supply chamber **262**.

When the pressure sensor **203** is placed in a vacuum atmosphere, gas of an unknown pressure can be supplied from the gas supply chamber **262** into the cavity portion **211** so that the absolute pressure of the supplied gas can be measured. Similarly, when the cavity portion **237** is sealed to provide a vacuum after the pressure sensor **203** is completed, the absolute pressure of the gas in the cavity portion **211** can be measured.

FIGS. **109** and **110** show a pressure sensor according to an eleventh embodiment of the present invention. The pressure sensor **204** shown in FIGS. **109** and **110** includes a pair of plate-like members **212**, **213**, protective layers **224**, a ground electrode terminal **246**, a connection line **247** and a filling portion **248**. The structure of other portions is the same as that of the pressure sensor **201**. The ground electrode terminal **246**, the connection line **247** and the filling portion **248** are part of the electrode layer **240**.

As shown in FIG. **110**, the paired plate-like members **212** and **213** project about 7 μm in the lamination direction from the surface of the semiconductor substrate **210**. In the horizontal direction in FIG. **110**, a movable portion **261** and a cavity portion **237** are provided between the paired plate-like member **212** and **213**.

The protective layers **224** cover the top surfaces of the paired plate-like members **212**, **213** in the lamination direction. The protective layers **224** are made of e.g. SiO_2. The protective layer **224** formed on the plate-like member **212** has an opening **224***a*. The filling portion **248** is provided to fill the opening **224***a*.

The ground electrode terminal **246** is a terminal for connection to external ground and provided at an appropriate position on the insulating cover **222**. The ground electrode terminal **246** is electrically connected to the filling portion **248** via the connection line **247**. The ground electrode terminal **246**, the connection line **247** and the filling portion **248** are made of e.g. Al and arranged to be electrically insulated from the fixed electrode terminal **241** and the movable electrode terminal **243**.

A method for manufacturing the pressure sensor **204** is described below with reference to FIGS. **111-124**, mainly as to the difference from the method for manufacturing the pressure sensor **201**.

First, a semiconductor substrate **210** in the form of a plate having an uniform thickness of about 100 to 1000 μm is prepared, and the semiconductor substrate **210** is processed to have a pair of plate-like members **212** and **213** described above. In this process, a step of forming protective layers **224** as shown in FIGS. **111** and **112** and a step of thinning the semiconductor substrate **210** in the lamination direction as shown in FIG. **113** are performed. The step of forming the protective layers **224** is performed by forming an SiO_2 layer having a thickness of about 0.5 μm on the surface of the semiconductor substrate **210** by CVD or thermal oxidation and then etching away unnecessary portions. The etching may be gas-phase anisotropic etching using the reaction between HF_2^- and SiO_2. Thinning the semiconductor substrate **210** in the lamination direction can be performed by gas-phase anisotropic etching using gas containing atomic fluorine.

In the next step, an insulating layer **221** is formed, as shown in FIG. **114**. This step is performed by e.g. thermally oxidizing the surface of the semiconductor substrate **210**. In this step, the insulating layer **221** is formed on the side surfaces of the plate-like members **212**, **213** as well.

In the next step, a semiconductor layer **230**A is formed, as shown in FIG. **115**. This step is performed by embedding a polycrystalline silicon material on the semiconductor substrate **210** except the portions where the plate-like members **212**, **213** exist, and allowing it to grow. Further, in this step, after the semiconductor layer **230**A has grown sufficiently, the surface of the semiconductor layer **230**A is flattened by CMP, using the surface of the protective layer **224** as the reference.

In the next step, an insulating cover **222** is formed, as shown in FIG. **116**. For instance, this step is performed by thermally oxidizing the surface of the semiconductor layer **230**A. The thickness of the insulating cover **222** formed in this step is e.g. 0.5 μm.

In the next step, an opening **222***a* is formed, as shown in FIGS. **117** and **118**. The opening **222***a* is formed to be sandwiched between the protective layers **224** on the paired support members **212** and **213**. Thereafter, the steps shown in FIGS. **91-101** of the method for manufacturing the pressure sensor **201** are performed, whereby the state shown in FIG. **119** is obtained.

In the next step, through-holes **223***a*, an opening **222***b* and an opening **224***a* are formed, as shown in FIGS. **120** and **121**.

This step is performed by arranging a resist of resin having openings corresponding to the through-holes **223***a* and the openings **222***b*, **224***a* and performing gas-phase etching using the reaction between HF_2^- and SiO_2.

In the next step, a metal layer **240**A is formed, as shown in FIG. **122**. The metal layer **240**A is a layer made of Al and formed to cover the insulating cover **222**, the insulating cover **223** and the protective layer **224**. In the opening **224***a*, the metal layer **240**A is formed directly on the plate-like member **212**. For instance, this step is performed by depositing Al by CVD.

In the next step, the metal layer **240**A is processed to provide an electrode layer **240**, as shown in FIGS. **123** and **124**. For instance, this step is performed by arranging a resist having the same shape as that of the electrode layer **240** as viewed in the lamination direction and removing unnecessary portions by gas-phase etching. Thereafter, the sacrificial layer **236** is removed, whereby the pressure sensor **204** shown in FIGS. **109** and **110** is completed.

In the pressure sensor **204**, the semiconductor substrate **210** can be connected to external ground via the ground electrode terminal **246**. This arrangement of the pressure sensor **204** allows the capacitance between the fixed electrode **242** and the movable portion **261** to be set precisely to a predetermined value. Thus, the pressure sensor **204** ensures more precise pressure measurement.

Further, the plate-like members **212** and **213** having a relatively high strength are arranged in such a manner as to penetrate the intermediate layer **230** in the lamination direction, so that the strength of the pressure sensor **204** is enhanced. In particular, since the movable portion **261** is held between the plate-like members **212** and **213**, the movable portion **261** is not easily deformed improperly even when undesirable pressure is applied to the intermediate layer **230**. This arrangement allows the capacitance between the fixed electrode **242** and the movable portion **261** to be set precisely to a predetermined value. Thus, the pressure sensor **204** ensures more precise pressure measurement.

The pressure sensor according to the present invention is not limited to the foregoing embodiments. The specific structure of each part of the pressure sensor according to the present invention can be varied in design in many ways. For instance, although the pressure sensors **202** and **203** have a structure based on the pressure sensor **201**, they may have a structure based on the pressure sensor **204**.

In the foregoing embodiment, the semiconductor substrate **210** is made of single-crystal silicon, whereas the semiconductor layer **230**A is made of polycrystalline silicon. Unlike this, however, the semiconductor substrate **210** may be made of polycrystalline silicon, whereas the semiconductor layer **230**A may be made of single-crystal silicon. Moreover, the sacrificial layer **236** may be made of single-crystal silicon or a resin having a low reactivity with HF_2^-.

FIGS. **125** and **126** show a pressure sensor according to a twelfth embodiment of the present invention. The pressure sensor **301** of this embodiment includes a semiconductor structure **310**, an insulating layer **320**, semiconductor films **331**, **332**, connection terminals **341**, **344**, **345**, connection lines **342**, **346**, conductive portions **343**, **347** and gas supply spaces **351**, **352**, **354** and a closed space **353**. The gas supply spaces **351**, **352**, **354** are filled with air from the outside of the pressure sensor **301**. The closed space **353** is in a vacuum state.

The semiconductor structure **310** is made of e.g. a single semiconductor material made of single-crystal silicon (Si) and comprise a semiconductor substrate **311** in the form of a flat plate, a plate-like member **312** and wall portions **313**, **314**. On the surface of the semiconductor substrate **311**, an oxide film **311***a* made of e.g. silicon dioxide (SiO_2) and having a thickness of about 0.2 μm is provided. In the description given below, the x direction is one of the in-plane directions of the semiconductor substrate **311**, the y direction is the in-plane direction of the semiconductor substrate **311** which is perpendicular to the x direction, and the z direction is the direction perpendicular to both of the x direction and the y direction. As shown in FIG. **125**, as viewed in the z direction, the semiconductor structure **310** is in the form of a rectangle elongated in the x direction. As shown in FIG. **126**, the z direction corresponds to the lamination direction of the semiconductor substrate **311**.

The plate-like member **312** stands vertically in the z direction from the center of the semiconductor substrate **311** in the x direction. The plate-like member **312** extends along the substantially entire length of the semiconductor substrate **311** in the y direction. The dimension of the plate-like member **312** in the direction x is e.g. 10 μm, and that in the z direction is e.g. 100 μm. Oxide films **312***a* made of e.g. SiO_2 and having a thickness of about 0.2 μm are formed on the two side surfaces of the plate-like member **312** which are spaced from each other in the x direction.

The wall portion **313** stands vertically in the direction z from the left end of the semiconductor substrate **311** in the x direction in FIG. **126**. The wall portion **313** extends along the substantially entire length of the semiconductor substrate **311** in the y direction. An oxide film **313***a* made of e.g. SiO_2 and having a thickness of about 0.2 μm is formed on the right side surface of the wall portion **313** in the x direction.

The wall portion **314** projects vertically in the direction z from the right end of the semiconductor substrate **311** in the x direction in FIG. **126**. The wall portion **314** extends along the substantially entire length of the semiconductor substrate **311** in the y direction. An oxide film **314***a* made of e.g. SiO_2 and having a thickness of about 0.2 μm is formed on the left side surface of the wall portion **314** in the x direction.

Though not shown in FIGS. **125** and **126**, the semiconductor substrate **311** have wall portions similar to the wall portions **313**, **314** at the ends spaced from each other in the y direction. Thus, the semiconductor structure **310** has two hollow portions partitioned by the plate-like member **312** in an area surrounded by the four wall portions. The semiconductor film **331** and the gas supply spaces **351**, **352** are positioned in the hollow portion sandwiched between the plate-like member **312** and the wall portion **313** in the x direction. The semiconductor film **332**, the closed space **353** and the gas supply space **354** are positioned in the hollow portion sandwiched between the plate-like member **312** and the wall portion **314** in the x direction.

The semiconductor film **331** is a film made of polycrystalline silicon and having a thickness of about 4 μm in the x direction. The semiconductor film **331** has a length of e.g. 10 μm in the z direction and extends along the substantially entire length of the semiconductor substrate **311** in the y direction. Oxide films **331***a* made of e.g. SiO_2 and having a thickness of about 0.2 μm are formed on the two side surfaces of the semiconductor film **331** which are spaced from each other in the x direction. The semiconductor film **331** is positioned between the plate-like member **312** and the wall portion **313** in the x direction. The right side surface of the semiconductor film **331** in the x direction in FIG. **126** is parallel to the left side surface of the plate-like member **312**, and the distance between these two surfaces is e.g. 2 μm. The distance between the left side surface of the semiconductor film **331** and the right side surface of the wall portion **313** is e.g. 3 to 8 μm.

The semiconductor film **331** partitions one of the above-described hollow portions into two spaces, i.e., the gas supply space **351** between the wall portion **313** and the semiconductor film **331** and the gas supply space **352** between the semiconductor film **331** and the plate-like member **312**.

The semiconductor film **332** is a film made of polycrystalline silicon and having a thickness of about 4 μm in the x direction. The semiconductor film **332** has a length of e.g. 10 μm in the z direction and extends along the substantially entire length of the semiconductor substrate **311** in the y direction. Oxide films **332***a* made of e.g. SiO_2 and having a thickness of about 0.2 μm are formed on the two side surfaces of the semiconductor film **331** which are spaced from each other in the x direction. The semiconductor film **332** is positioned between the plate-like member **312** and the wall portion **314** in the x direction. The left side surface of the semiconductor film **332** in the x direction in FIG. **126** is parallel to the right side surface of the plate-like member **312**, and the distance between these two surfaces is e.g. 2 μm. The distance between the right side surface of the semiconductor film **332** and the left side surface of the wall portion **314** is e.g. 3 to 8 μm.

The semiconductor film **332** partitions the other one of the above-described hollow portions into two spaces, i.e., the closed space **353** between the semiconductor film **332** and the plate-like member **312** and the gas supply space **354** between the semiconductor film **332** and the wall portion **314**.

The insulating layer **320** is made of e.g. SiO_2 and formed on the semiconductor structure **310**. The insulating layer **320** has openings **320***a*, **320***b* and **320***c* above the gas supply spaces **351**, **352** and **354**. Outside air can flow into the gas supply spaces **351**, **352**, **354** through the openings **320***a*, **320***b*, **320***c*. The insulating layer **320** further has openings **320***d* that expose the connection terminals **341**, **344**, **345**, the connection lines **342**, **346** and the conductive portions **343**, **347**.

The connection terminal **341** is a terminal used for electrical connection to the outside and connected to the conductive portion **343** via the connection line **342**. The conductive portion **343** is electrically connected to the semiconductor film **331**.

The connection terminal **344** is a terminal used for electrical connection to the outside and electrically connected to e.g. the upper end of the wall portion **314** in the z direction Since the semiconductor structure **310** is formed as a single integral unit, the connection terminal **344** is electrically connected to the plate-like member **312** as well.

The connection terminal **345** is a terminal used for electrical connection to the outside and connected to the conductive portion **347** via the connection line **346**. The conductive portion **347** is electrically connected to the semiconductor film **332**.

The operation and advantages of the pressure sensor **301** are described below.

In the pressure sensor **301**, the semiconductor films **331** and **332** are not fixed in the x direction but are deformable due to the small thickness in the x direction, thereby functioning as movable electrodes. Since the semiconductor film **331** is closer to the plate-like member **312** than to the wall portion **313**, the left side surface of the plate-like member **312** in the x direction functions as the fixed electrode relative to the semiconductor film **331**. Similarly, since the semiconductor film **332** is closer to the plate-like member **312** than to the wall portion **314**, the right side surface of the plate-like member **312** in the x direction functions as the fixed electrode relative to the semiconductor film **332**. The plate-like member **312** is electrically connected to the connection terminal **344**, and the semiconductor films **331** and **332** are electrically connected to the connection terminals **341** and **345**, respectively. This arrangement allows proper detection of capacitance between each of the fixed electrodes and each of the movable electrodes.

As described above, the distance between the left side surface of the plate-like member **312** in the x direction and the semiconductor film **331** and the distance between the right side surface of the plate-like member **312** in the x direction and the semiconductor film **332** are equal to each other, and the semiconductor films **331** and **332** have the same size and shape as viewed in the x direction. Thus, when the semiconductor films **331** and **332** are not deformed, the output values from the connection terminal **341** and the connection terminal **342** are substantially the same.

The semiconductor film **331** receives pressure in the x direction from both of the gas introduced into the gas supply space **351** and the gas introduced into the gas supply space **352**. In this embodiment, the same outside air is introduced into the two gas supply spaces **351** and **352**, so that the pressure applied to the semiconductor film **331** is balanced. Thus, the capacitance between the semiconductor film **331** and the plate-like member **312** does not change, so that the output from the connection terminal **341** serves as a constant reference value.

On the other hand, the semiconductor film **332** is sandwiched in the x direction between the vacuum closed space **353** and the gas supply space **354** in which outside air is introduced. Thus, the semiconductor film **332** receives, from the outside air introduced into the gas supply space **354**, a pressure corresponding to the pressure of the outside air, and is hence deformed. Thus, the capacitance between the semiconductor film **332** and the plate-like member **312** changes in accordance with the pressure of the outside air, and the output from the connection terminal **345** is a value corresponding to the changing capacitance. By comparing this value with the reference value obtained through the connection terminal **341**, the change in capacitance between the semiconductor film **332** and the plate-like member **312** is calculated, and based on the change in capacitance, the pressure of the outside air is calculated. Thus, the pressure sensor **301** is suitable for measuring the absolute pressure of the outside air.

A method for manufacturing the pressure sensor **301** is described below with reference to FIGS. **127**-**145**.

First, a semiconductor material **310**A made of a single-crystal silicon and in the form of a rectangular parallelepiped is prepared, and the semiconductor material **310**A is processed to provide a semiconductor structure **310**.

To process the semiconductor material **310**A, an insulating layer **321** of SiO_2 is formed on the surface of the semiconductor material **310**A. This step can be performed by thermally oxidizing the surface of the semiconductor material **310**A. Alternatively, chemical vapor deposition (CVD) may be employed.

In the next step, as shown in FIGS. **127** and **128**, openings **322** and **323** are formed in the insulating layer **321** to expose the surface of the semiconductor material **310**A. The opening **322** is formed in an area that overlaps the area where the gas supply spaces **351**, **352** and the semiconductor film **331** are to be formed, as viewed in the z direction. The opening **323** is formed in an area that overlaps the area where the closed space **353**, the gas supply space **354** and the semiconductor film **332** are to be formed, as viewed in the z direction. For instance, this step is performed by providing a resist of resin which exposes the portions where the openings **322** and **323** are to be formed and performing gas-phase etching using the reaction between fluorine-containing molecular ions (HF_2^-) and SiO_2. For instance, HF_2^- can be obtained by reacting hydrogen fluoride (HF) with water vapor. For instance, HF can be obtained by reacting atomic fluorine (F) or molecular fluorine (F_2), which is obtained by e.g. decomposing carbon tetrafluoride (CF_4) gas or trifluoromethane (CHF_3) gas, with water vapor. Since Si which is not oxidized does not easily react with HF_2^-, the semiconductor layer **310**A is not removed by the etching and hence remains. Instead of the gas-phase etching, wet etching using aqueous solution of hydrogen fluoride (HF) may be performed.

In the next step, etching in the z direction is performed with respect to the semiconductor material **310**A, as shown in FIG. **129**. Through this step, the semiconductor structure **310** is obtained as a remaining portion of the semiconductor material **310**A. This step can be performed by Si-DRIE (deep reactive ion etching) utilizing the Bosch (registered trademark) process. The Bosch process is a process in which etching and side wall protection are performed repeatedly and which allows etching with a high aspect ratio. As a result of this step, the portions of the semiconductor material **310**A which are covered with the insulating layer **321** remain, whereby the plate-like member **312**, the wall portions **313**, **314** and the wall portions spaced in the y direction are provided. The etching time is adjusted so as not to penetrate the semiconductor material **310** in the z direction, so that the bottom of the semiconductor material **310**A remains to become the semiconductor substrate **311**.

In the next step, oxide films **311***a*, **312***a*, **313***a* and **314***a* are formed, as shown in FIG. **130**. This step can be performed by thermally oxidizing the surface of the semiconductor structure **310**. The films can be formed by depositing SiO_2 by CVD.

In the next step, a semiconductor layer **331**A and a semiconductor layer **332**A are formed, as shown in FIG. **131**. The semiconductor layer **331**A is made of polycrystalline silicon and formed to fill the space between the wall portion **313** and the plate-like member **312**. The semiconductor layer **332**A is made of polycrystalline silicon and formed to fill the space between the wall portion **314** and the plate-like member **312**. This step is performed by e.g. epitaxial growth of polycrystalline silicon on the semiconductor substrate **311** by CVD. Also in this step, the surfaces of the semiconductor layers **331**A and **332**A are flattened. The flattening can be performed by e.g. chemical mechanical polishing (CMP).

In the next step, as shown in FIG. **132**, an insulating layer **324**A is formed on the surface of the semiconductor layer **331**A, and an insulating layer **325**A is formed on the surface of the semiconductor layer **332**A. The insulating layer **324**A is formed to cover the entire portion of the semiconductor layer **331**A which is not covered with the insulating layer **321**. The insulating layer **325**A is formed to cover the entire portion of the semiconductor layer **332**A which is not covered with the insulating layer **321**. The insulating layers **324**A and **325**A are made of SiO_2 and have a thickness of e.g. about 0.8 μm. This step can be performed by thermal oxidation or CVD. By this step, the openings **322** and **323** are closed by the insulating layers **324**A and **325**A.

In the next step, insulating layers **324**, **325** and openings **322***a*, **322***b*, **323***a*, **323***b* are formed, as shown in FIGS. **133** and **134**. The insulating layer **324** is formed in an area that overlaps the area where the semiconductor film **331** is to be formed, as viewed in the z direction. The insulating layer **325** is formed in an area that overlaps the area where the semiconductor film **332** is to be formed, as viewed in the z direction. The opening **322***a* is formed to expose the semiconductor layer **331**A in an area that overlaps the area where the gas supply space **352** is to be formed, as viewed in the z direction. The opening **322***b* is formed to expose the semiconductor layer **331**A in an area that overlaps the area where the gas supply space **351** is to be formed, as viewed in the z direction. The opening **323***a* is formed to expose the semiconductor layer **332**A in an area that overlaps the area where the closed space **353** is to be formed, as viewed in the z direction. The opening **323***b* is formed to expose the semiconductor layer **332**A in an area that overlaps the area where the gas supply space **354** is to be formed, as viewed in the z direction. This step can be performed by the same technique as that used for forming the openings **322** and **323**.

In the next step, a semiconductor film **331** and a semiconductor film **332** are formed, as shown in FIG. **135**. In this step, etching in the z direction is performed with respect to the semiconductor layers **331**A and **332**A. For instance, the etching in this step can be performed by Si-DRIE utilizing the Bosch (registered trademark) process. In this step, the semiconductor layer **30** under the insulating layers **324**, **25** remains, whereby semiconductor films **331**, **332** are provided.

In the next step, oxide films **331***a*, **32***a* are formed, as shown in FIG. **136**. For instance, this step can be performed by thermal oxidation or CVD.

In the next step, sacrificial layers **326**A, **327**A, **328**A and **329**A are formed, as shown in FIG. **137**. For instance, the sacrificial layers **326**A, **327**A, **328**A and **329**A are made of polycrystalline silicon or a resin such as polyimide. The sacrificial layer **326**A is formed to fill the space where the gas supply space **351** is to be formed. The sacrificial layer **327**A is formed to fill the space where the gas supply space **352** is to be formed. The sacrificial layer **328**A is formed to fill the space where the closed space **353** is to be formed. The sacrificial layer **329**A is formed to fill the space where the gas supply space **354** is to be formed.

In the next step, insulating layers **326**, **327**, **328** and **329** are formed on the surfaces of the sacrificial layers **326**A, **327**A, **328**A and **329**A as shown in FIG. **138**. This step can be performed by thermal oxidation or CVD.

In the next step, as shown in FIGS. **139** and **140**, openings **326***a*, **327***a*, **328***a* and **329***a* are formed in the insulating layers **326**, **327**, **328** and **329**, an opening **324***a* is formed in the insulating layer **324**, an opening **325***a* is formed in the insulating layer **325**, and an opening **321***a* is formed in the insulating layer **321**. This step is performed by gas-phase etching using the reaction between HF_2^- and SiO_2 by using a resist of resin having openings corresponding to the openings **321***a*, **324***a*, **325***a*, **326***a*, **327***a*, **328***a* and **329***a*.

In the next step, a metal layer **340** is formed, as shown in FIG. **141**. The metal layer **340** is made of e.g. Al and formed to cover the insulating layers **321**, **324**, **325**, **326**, **327**, **328** and **329**. For instance, this step can be performed by depositing Al by CVD.

In the next step, as shown in FIGS. **142** and **143**, the metal layer **340** is processed to provide connection terminals **341**, **344**, **345**, connection lines **342**, **346** and conductive portions **343**, **347**. For instance, this step is performed by arranging a resist having a shape corresponding to the shapes of the connection terminals **341**, **344**, **345**, connection lines **342**, **346** and conductive portions **343**, **347** and removing unnecessary portions of the Al metal layer by gas-phase etching.

In the next step, sacrificial layers **326**A, **327**A, **328**A and **329**A are removed, as shown in FIG. **144**. For instance, this step can be performed by gas-phase etching using gas containing xenon fluoride (XeF_2). By the removal of the sacrificial layers **326**A, **327**A, **328**A and **329**A, cavity portions **351**A, **352**A, **353**A and **354**A are provided.

In the next step, openings **326***a*, **327***a*, **328***a* and **329***a* are sealed, and an insulating layer **320** is formed, as shown in

FIG. **145**. This step is performed by depositing SiO_2 on the insulating layers **321**, **324**, **325**, **326**, **327**, **328** and **329** by low pressure chemical vapor deposition (LPCVD) or plasma CVD in a vacuum atmosphere. In this step, SiO_2 grows from the edges of the openings **326***a*, **327***a*, **328***a* and **329***a* toward the center, so that the sealing portion formed in this step tends to be thin at the center. In this embodiment, the insulating layer **320** is deposited to a thickness sufficient to cover the connection terminals **341**, **344**, **345**, the connection lines **342**, **346** and the conductive portions **343**, **347**. When a mask is used, SiO_2 may not be deposited on the connection terminals **341**, **344**, **345**, the connection lines **342**, **346** and the conductive portions **343**, **347**.

In the next step, openings **320***a*, **320***b*, **320***c* and **320***d* are formed, whereby the pressure sensor **301** shown in FIGS. **125** and **126** is completed. The step of forming the openings **320***a*, **320***b*, **320***c* and **320***d* is performed by gas-phase etching using the reaction between HF_2^- and SiO_2 by using a resist of resin having openings corresponding to the openings **320***a*, **320***b*, **320***c* and **320***d*. In this embodiment, SiO_2 is deposited on the connection terminals **341**, **344**, **345**, the connection lines **342**, **346** and the conductive portions **343**, **347** in the previous step. Thus, by forming the opening **320***d*, the connection terminals **341**, **344**, **345** are exposed outside the insulating layer **320**. According to this manufacturing method, as shown in FIG. **126**, the surfaces of the connection terminals **341**, **344**, **345**, the connection lines **342**, **346** and the conductive portions **343**, **347** become lower than the surface of the insulating layer **320**. When a mask is provided on the connection terminals **341**, **344**, **345**, the connection lines **342**, **346** and the conductive portions **343**, **347** in the previous step, SiO_2 may not be deposited on the connection terminals **341**, **344**, **345**, the connection lines **342**, **346** and the conductive portions **343**, **347**. In this case, opening **320***d* may not need to be formed.

The operation and advantages of the pressure sensor **301** are described below.

As noted before, in the pressure sensor **301**, the right and left side surfaces, which are spaced from each other in the direction x, of the plate-like member **312** standing from the surface of the semiconductor substrate **311** function as fixed electrodes, whereas the side surfaces of the semiconductor films **331**, **332** which face the plate-like member **312** in the x direction function as movable electrodes. In this way, in the pressure sensor **301**, the fixed electrodes and the movable electrodes stand on the semiconductor substrate **311** in the z direction. With this arrangement, fixed electrodes and movable electrodes can be made in a relatively small area of the semiconductor substrate **311**, as viewed in the z direction. Accordingly, the area of the pressure sensor **301** as viewed in the z direction can be made smaller, which leads to size reduction of the pressure sensor **301**. Thus, the pressure sensor can be set in a small area in e.g. an electronic device.

According to the manufacturing method of this embodiment, the plate-like member **312** standing in the z direction is formed easily by performing etching in the z direction with respect to the semiconductor material **310**A. Moreover, the semiconductor films **331** and **332** are formed easily by performing etching in the z direction with respect to the semiconductor layers **331**A, **332**A.

In the foregoing embodiment, the space between the plate-like ember **312** and the semiconductor film **332** is the closed space **353**, whereas the space between the semiconductor film **332** and the wall portion **314** is the gas supply space **354**. However, these may be replaced with each other. The pressure sensor may be designed to enclose gas of a given pressure in the closed space **353** and measure the relative pressure between the gas and the pressure of the outside air.

FIGS. **146**-**153** show other embodiments of the present invention. In these figures, the elements which are identical or similar to those of the foregoing embodiments are designated by the same reference signs as those used for the foregoing embodiments.

FIGS. **146** and **147** show a pressure sensor according to a thirteenth embodiment of the present invention. The pressure sensor **302** of this embodiment includes a gas supply space **353'** instead of the closed space **353**, and openings **320***e*, **320***f* instead of the openings **320***a*, **320***b*, **320***c*. The structures of other parts of the pressure sensor **302** are the same as those of the pressure sensor **301**.

The openings **320***e* are provided between the wall portion **313** and the semiconductor film **331** and between the plate-like member **312** and the semiconductor film **332** in the x direction. The opening **320***e* is connected via e.g. a pipe to a gas source capable of supplying gas of a given pressure. Thus, the gas supply spaces **351** and **353'** are filled with the gas of a given pressure supplied from the gas source.

The openings **320***f* are provided between the semiconductor film **331** and the plate-like member **312** and between the semiconductor film **332** and the wall portion **314**. Outside air is taken in through the openings **320***f*, so that outside air whose pressure is to be measured is introduced into the gas supply spaces **352**, **354**.

In the pressure sensor **302**, the semiconductor film **331** is deformed due to the pressure difference between the gas of a given pressure introduced into the gas supply space **351** and the outside air introduced into the gas supply space **352**. The deformation causes a change in capacitance between the semiconductor film **331** and the plate-like member **312**, and the change is detected through the connection terminal **341**. On the other hand, the semiconductor film **332** is deformed due to the pressure difference between the gas of a given pressure introduced into the gas supply space **353'** and the outside air introduced into the gas supply space **354**. The deformation causes a change in capacitance between the semiconductor film **332** and the plate-like member **312**, and the change is detected through the connection terminal **345**.

For instance, when the pressure of the gas from the gas source is higher than the pressure of the outside air, the semiconductor film **331** is deformed toward the plate-like member **312** in the x direction, whereas the semiconductor film **332** is deformed to be away from the plate-like member **312**. Thus, the capacitance between the semiconductor film **331** and the plate-like member **312** increases in accordance with the pressure difference between the gas from the gas source and the outside air, whereas the capacitance between the semiconductor film **332** and the plate-like member **312** decreases in accordance with the pressure difference. The capacitances show the opposite behavior when the pressure of the gas from the gas source is lower than the pressure of the outside air.

Thus, the difference between the change in capacitance detected through the connection terminal **341** and that detected through the connection terminal **345** is twice the change in capacitance at one of the semiconductor films **331** and **332**. In the pressure sensor **302**, therefore, the difference between the changes in capacitance detected respectively through the connection terminal **341** and the connection terminal **345** is halved, and the pressure of the outside air relative to the pressure of the gas from the gas supply is calculated based on the halved value.

In the pressure sensor **302** having the above-described structure, a change in capacitance, which is usually of a small value, is detected as doubled, which allows more precise measurement.

Unlike the above, outside air may be introduced through the openings **320***e*, while gas of a given pressure may be introduced through the openings **320***f*.

FIG. **148** shows a pressure sensor according to a fourteenth embodiment of the present invention. In the pressure sensor **303** of this embodiment, the plate-like member **312** does not comprise part of the semiconductor structure **310**, but is made of polycrystalline silicon. The structures of the other parts of the pressure sensor **303** are the same as those of the pressure sensor **301**. In the pressure sensor **303**, the plate-like member **312** is not electrically connected to the wall portion **314**. Thus, the connection terminal **344** is formed directly on the plate-like member **312** in the z direction for electrical connection to the plate-like member **312**.

In the process of manufacturing the pressure sensor **303**, etching of the semiconductor material **310**A is performed such that the portion between the wall portion **313** and the wall portion **314** in the x direction is entirely etched away. Thereafter, a semiconductor layer **330**A is formed to fill the space between the wall portion **313** and the wall portion **314**, and an insulating layer **321'** is formed, along with insulating layers **324**, **325**, on the semiconductor layer **330**A, as shown in FIG. **149**. Thereafter, etching in the z direction is performed with respect to the semiconductor layer **330**A, whereby the plate-like member **312** as well as the semiconductor films **331**, **332** are provided as remaining portions of the semiconductor layer **330**A.

With this pressure sensor **303**, movable electrodes and fixed electrodes, which require precise processing, are formed at the same time. Thus, the manufacturing process is simple.

FIG. **150** shows a pressure sensor according to a fifteenth embodiment of the present invention. In the pressure sensor **304** shown in FIG. **150**, the plate-like member **312** and the wall portions **313**, **314** are made of polycrystalline silicon, and the connection terminal **344** is formed directly on the plate-like member **312** in the z direction for electrical connection to the plate-like member **312**. In the pressure sensor **304**, the wall portions provided at the ends spaced in the y direction in the pressure sensor **301** are not provided, to insulate the plate-like member **312** from the semiconductor films **331**, **332**. The structures of the other parts of the pressure sensor **304** are the same as those of the pressure sensor **301**.

The pressure sensor **304** is made of the semiconductor material **310**B shown in FIG. **151**, instead of the semiconductor material **310**A of single-crystal silicon shown in FIG. **128**. The semiconductor material **310**B comprises a semiconductor substrate **311** in the form of a flat plate, an oxide film **311***a* formed on the semiconductor substrate **311**, and a semiconductor layer **330**A formed on the oxide film **311***a*.

To manufacture the pressure sensor **304**, an insulating layer **321** as shown in FIGS. **152** and **153** is formed, and etching in the z direction is performed with respect to the semiconductor layer **330**A. The insulating layer **321** of this embodiment has openings **322***c*, **322***d*, **323***c* and **323***d* penetrating in the y direction, instead of the openings **322***a*, **322***b*, **323***a*, **323***b*. Thus, by the etching, the semiconductor films **331**, **332**, the plate-like member **312** and the wall portions **313**, **314** are formed at one time, as remaining portions of the semiconductor layer **330**A. The subsequent steps are the same as those for manufacturing the pressure sensor **301**. In this embodiment, however, in or before forming the insulating layer **320**, the space between the semiconductor film **332** and the plate-like member **312** are closed by an insulating material at the ends spaced from each other in the y direction to form the closed space **353**.

As compared with the pressure sensor **301**, the pressure sensor **304** can be manufactured through a smaller number of etching steps and hence realizes a simple manufacturing process.

A pressure sensor similar to the pressure sensors **301**, **303** can be manufactured by processing the semiconductor material **310**B in a manner similar to the semiconductor material **310**A. In this case, in forming the semiconductor structure **310**, the step of etching the semiconductor material **310**A using gas containing F is replaced with the step of etching the semiconductor material **310**B using gas containing HF.

The pressure sensor according to the present invention is not limited to the foregoing embodiments. The specific structure of each part of the pressure sensor and the specific way of each step of its manufacturing method according to the present invention can be varied in design in many ways. For instance, although the pressure sensors **303** and **304** have a structure based on the pressure sensor **301**, it may have a structure based on the pressure sensor **302**.

Although the pressure sensor **301** includes a semiconductor film **331** for outputting a reference value, a capacitor capable of outputting the value equal to the reference value may be provided in the circuit in which the pressure sensor is arranged. In this case, the left half in FIG. **126** of the pressure sensor **301** can be omitted.

The invention claimed is:

1. A pressure sensor comprising a movable electrode and a fixed electrode arranged in parallel to each other, further comprising:

- a semiconductor substrate;
- a first insulating layer formed on the semiconductor substrate;
- a semiconductor layer formed on the semiconductor substrate, with the first insulating layer intervening therebetween;
- a second insulating layer formed on the semiconductor layer;
- a first cavity portion formed in the semiconductor substrate;
- a second cavity portion overlapping the first cavity portion as viewed in a lamination direction and formed in contact with the second insulating layer, wherein:
- the fixed electrode faces the second insulating layer across the second cavity portion;
- the movable electrode is provided at a portion of the semiconductor layer which is sandwiched between the first cavity portion and the second cavity portion;
- the movable electrode includes a through-hole penetrating the semiconductor layer in the lamination direction; and
- the pressure sensor further comprises a sealing member which is disposed within the through-hole and seals the through-hole.

2. The pressure sensor according to claim **1**, wherein the sealing member is made of a different material from the semiconductor layer.

3. The pressure sensor according to claim **2**, wherein the semiconductor layer is made of silicon, whereas the sealing member is made of silicon dioxide.

4. The pressure sensor according to claim **1**, further comprising a third insulating layer facing the second insulating layer across the second cavity portion,

wherein the fixed electrode is provided on the third insulating layer.

5. The pressure sensor according to claim **1**, further comprising a vent hole penetrating the fixed electrode in the lamination direction, one end of the vent hole in the lamination direction reaching the second cavity portion.

6. The pressure sensor according to claim **1**, further comprising a movable electrode terminal electrically connected to the semiconductor layer.

7. The pressure sensor according to claim **1**, wherein the semiconductor substrate is provided with a pair of plate-like members projecting in the lamination direction and facing each other, and

the movable electrode and the second cavity portion are sandwiched between the paired plate-like members.

8. The pressure sensor according to claim **7**, further comprising a protective layer formed on the paired plate-like members and including an opening which exposes a surface of at least one of the plate-like members, and a ground electrode terminal electrically connected to the semiconductor substrate via the opening.

* * * * *